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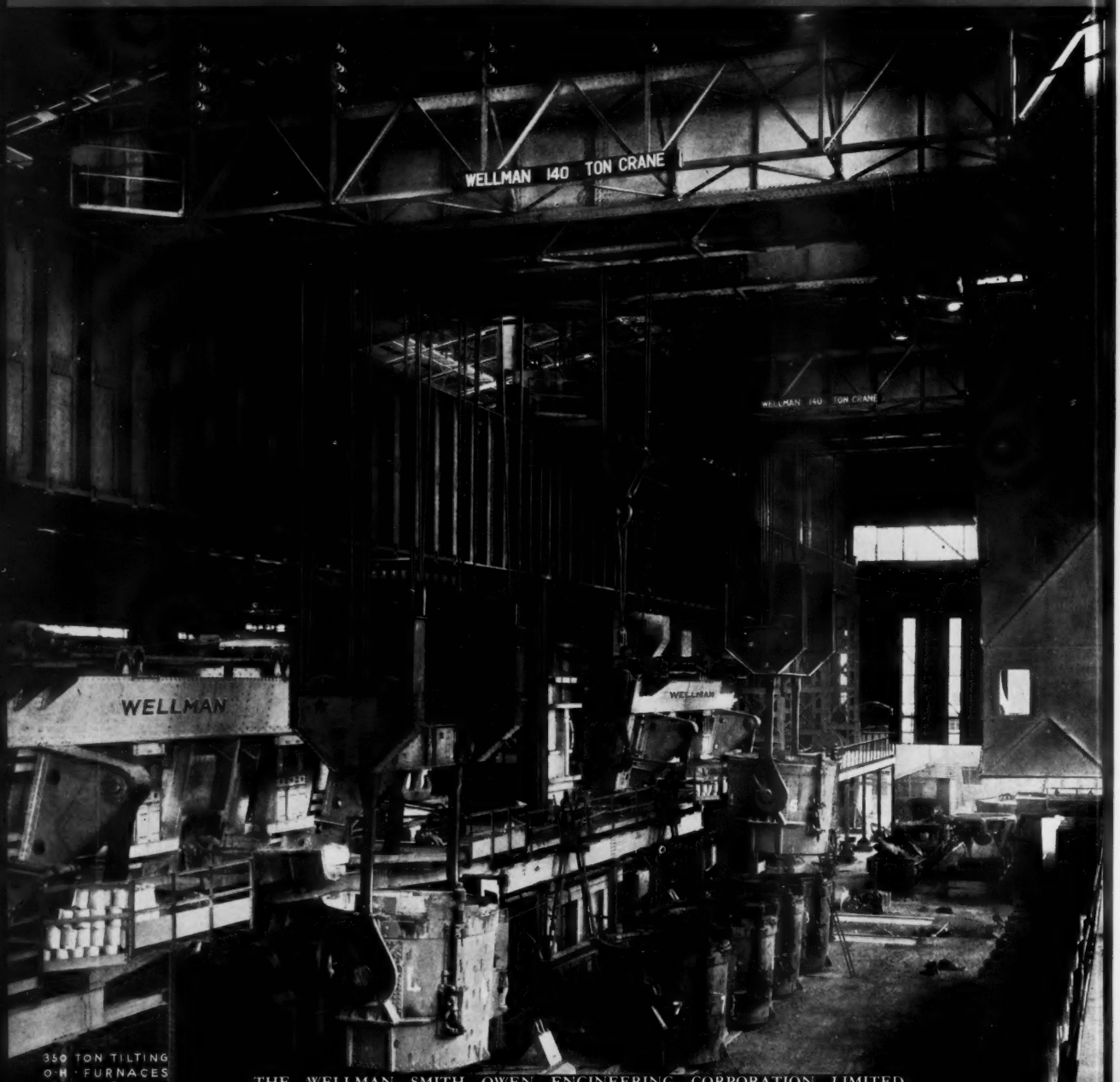
The Modern Steelworks



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THE WELLMAN SMITH OWEN ENGINEERING CORPORATION LIMITED
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CAPTAIN H. LEIGHTON DAVIES, C.B.E., J.P.

CAPTAIN HECTOR LEIGHTON DAVIES, eldest son of the late Sir John C. Davies, Managing Director of Baldwins, Ltd., was born at Sebastapool, Panteg, Mon., in 1894. He was educated at Malvern College and at the Technical College, Swansea, and then spent a year, 1913-1914, in Germany.

In September, 1914, he joined the Swansea Battalion, the Welch Regiment, and was mentioned in Despatches. He was invalided out in 1915 and became Assistant to Mr. James Peech in the Shell Steel Department of the Ministry of Munitions, but after two years with the Ministry he went to Baldwins, Ltd., to supervise extensions to their Gowerton Works. In 1921 he was appointed General Manager of the steel and tinplate interests of Baldwins, Ltd., in South Wales, and was elected a Director. When the company was reconstructed in 1927 he resigned his seat on the Board and was appointed General Manager of the South Wales Branch and the Monmouthshire Branch, but relinquished the latter in 1933.

At the outbreak of the last war Captain Davies accepted the position of Director of Scrap and Tinplate, Iron and Steel Control, Ministry of Supply, but asked to be released at the end of 1939, as he had, in November, been re-elected to the Board of Baldwins, Ltd. In 1945, on the amalgamation of Baldwins, Ltd., and Richard Thomas and Co., Ltd., he became a Director of Baldwins (Holdings), Ltd., and a General Manager of Richard Thomas and Baldwins, Ltd., in charge of their steel and tinplate interests in West Wales. In July, 1947, on the formation of The Steel Company of Wales, Ltd., Captain Davies was elected to the Board, and in September, 1947, was appointed Assistant Managing Director. In October, 1947, he was elected a Director of The Steel Company of Wales (Lysaght Works), Ltd.

During the last war Captain Davies was a Member of the Wales Regional Board of the Ministry of Aircraft Production, and from 1940 to 1945 he was Area Controller (Wales) of the Emergency Services Organisation of the Iron and Steel Control.

Captain Davies has always played a prominent part in encouraging metallurgical research and its application to the steel and tinplate industries of South Wales. In 1946 he became a Member of Council of the British Iron and Steel Research Association, and acts as Chairman of its Coatings Committee. He is a Member of the Council and Executive of the British Iron and Steel Federation, and has been a member of the Central Council of Wages since 1928 ; he has acted as Chairman of the Federation's Scrap Committee since 1937. He is also a Member of Council of the Federation of British Industries, Vice-Chairman of the Tinplate Conference and of the Welsh Plate and Sheet Manufacturers' Association, and Chairman of the Welsh Plate and Sheet Trades Joint Industrial Council. Captain Davies also has a long record of service on public bodies. He became a Justice of the Peace in 1925, and among his many interests at the moment are : President of the Swansea Chamber of Commerce, Inc. ; President of the Incorporated Swansea Exchange ; Chairman of Swansea and District Employment Committee ; Member of Council of the University College of Swansea ; Member of the Welsh Board for Industry ; and Member of Council, Industrial Welfare Society, Inc. He has also served for over 21 years on the Local District Council. He was awarded the C.B.E. in 1941.

In 1911 Captain Davies became a Life Member of The Iron and Steel Institute and was elected a Vice-President in 1944. He was President of the Swansea and District Metallurgical Society in 1947.

Captain H. Leighton Davies, C.B.E., J.P.

Vice-President

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

The Phase-Contrast Incident-Light Microscope

By F. W. Cuckow, M.Sc., F.Inst.P.

SYNOPSIS

A review is given of experiments in the comparative microscopy of metals leading to the conclusion that new information can be gained from a knowledge of the various levels existing in the surface of the prepared metallurgical specimen. The means already available for the assessment of these levels are discussed. A new instrument for this work, a phase-contrast incident-light microscope, is described. A comparative microscope is also described in which a single field of view is divided into two parts, one of which is seen under phase-contrast conditions and the other under normal microscopical conditions. The dividing line can be moved across the field of view. Photomicrographs from the instrument are shown. These indicate that the instrument is a useful addition to the tools available to the metallurgist.

Introduction

THE metallurgist's normal tool for the examination of the microstructure of metal specimens is the vertical-illumination microscope, or as it might better be called, the incident-light microscope. The specimens are prepared by well-established techniques usually involving polishing of the surface by mechanical or electrolytic means, followed by etching with selected reagents to remove the layer of flowed metal associated with mechanical polishing, and also to reveal the microstructure generally.

The etching process renders grain boundaries visible on account of preferential attack at these discontinuities in the surface of pure specimens and as a result of differential etching rates in the case of specimens containing more than one constituent or containing one constituent only, but with a variety of orientations.

In general the grain boundaries appear as black dividing lines between areas of materials which can be identified by their characteristic shape as defined by the boundary or by their inner appearance, the latter being assessed in relation to the particular etching reagent used.

Microscopical metallurgy is sometimes aided by special treatment of the specimen, such as heating, which can give rise to differential coloration effects by action on the surface layers of the various constituents.

It has been commonly assumed that the limitations of the light microscope in metallography are largely due to the finite resolving power available in that instrument, this being due in turn to the finite wavelength of the radiation used in viewing the specimen. The tendency has therefore been to exploit the possibilities of higher-power microscopy offered by the use of shorter-wavelength radiations, first the shorter-wavelength region of the visible spectrum, then ultra-violet, and in recent years the much shorter wavelength associated with high-velocity electrons as used in the electron microscope.

New information has certainly been gained by such methods purely on account of their greater resolving power, but it is the purpose of this paper to show that certain other advantages, gained as incidentals in the attainment of higher resolving power, have led to the design of a new metallurgical microscope using light.

To appreciate the advantages to be gained from the instrument, it is perhaps best to survey briefly the work which led to its conception.

COMPARATIVE MICROSCOPY OF METALS

In an assessment of the usefulness of the electron microscope in microscopical metallography, a number of metal specimens had been examined by means of that instrument and by means of the normal metallurgical light microscope.

The best work in electron metallography is as yet carried out through the agency of thin replicas of the specimens which are examined in the electron microscope in place of the originals. Such replicas may hope to carry over information on the geometric nature of the surface of the specimen, but in view of the indirect

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Mr. Cuckow, who was with the Metallurgy Division of the National Physical Laboratory at the time this paper was written, is now at the Chester Beatty Research Institute, Royal Cancer Hospital, London.

nature of the examination some doubts may be expressed as to the interpretation of the final micrographs. In such circumstances the best method of attack is thought to be by approach from as many directions as possible. If the same impression of the shape of the surface were obtained from each line of attack it would be reasonable to assume that it was a true impression. For this purpose the specimens were examined on a normal metallurgical microscope and also on an electron microscope. In the latter case, replicas of the specimen were made by two methods.

For our present purpose we will consider two micrographs only (*see* Figs. 7 and 8), obtained from a nickel–chromium steel which had been heat-treated to bring out " intermediate transformation products,"[1] and had the following analysis :

Carbon ...	0·27%	Chromium	0·99%
Nickel ...	2·81%	Molybdenum	0·35%

Etching was by nitric acid in alcohol. The figures are, respectively, a photomicrograph prepared under oil immersion at a magnification of 1500 diameters and an electron micrograph prepared at 1000 diameters from a plastic film (" Formvar ")[2] replica. The pictures have subsequently been brought to the same magnification for purposes of comparison.

The electron micrograph shows a considerable gain in picture sharpness over the photomicrograph. The photomicrograph shows boundaries clearly as black lines and the metallurgist can distinguish between the various areas so outlined by differences in their inner structure, but it is not easy as the reflection factors of the various parts are closely similar and no simple contrast arises.

On the other hand, the electron micrograph of a plastic film replica introduces a high degree of contrast between the two phases present in the specimen. The " intermediate transformation product " is revealed as a relatively rapid etching phase so that it lies below the general level of the martensitic matrix, this difference in surface level leading to greater thickness of the replica film and so to a dark area in the electron micrograph.

The normal metallurgical light microscope gives no information on this question of surface levels, in fact it is impossible to deduce the geometric form of the surface of the specimen from the photomicrograph, whereas the electron micrograph is easily interpreted on a qualitative basis from " picture brightness " to " thickness of replica film." On the assumption that the replica film is flat on one face, and faithfully follows the surface contours on the other, this means that the geometric nature of the surface of the specimen can be confidently deduced from such an electron micrograph as Fig. 8.

One outstanding advantage gained from this electron micrograph, therefore, is in no way associated with the admittedly higher resolution, but simply with the ability of the method to appreciate variations in surface level and, therefore, to distinguish between metallurgical phases largely in terms of their etching rates.

It may be pointed out that the " depth sensitivity " of the replica method is extremely high. The total range of levels exhibited in Fig. 8 probably does not exceed the millionth part of an inch, *i.e.*, 250 Å, or 0·0000025 cm.

METHODS AVAILABLE FOR THE ASSESSMENT OF SURFACE LEVELS

The previous section has shown that useful information can be obtained from suitably prepared metallurgical specimens by an analysis of the levels of the various parts of the surface. It is desirable therefore to survey the various known methods of assessing surface levels.

Gross variations in level can be observed as out-of-focus effects on normal metallurgical microscopes. For example, in work on electrolytically polished copper specimens[3] it was noticed that the greater part of the specimen stayed in focus as the traversing controls on a normal metallurgical microscope were operated, but occasionally a defocused area would come into the field of view. The centres of such defocused areas, however, could be brought into focus by readjusting the microscope, and calibration of the focusing controls for direction of movement lead to the decision that the defocused areas were " hills " on the surface of the specimen surmounted by flat " plateaux " with sharply defined edges. It was these plateaux which came clearly into view on refocusing on an otherwise defocused area. Further, by calibration of the screw controlling the fine focus it was possible to determine the height of the hills by focusing first on the plateau and then on the general background. It appeared that these hills had been formed during the electrolytic polishing process by the protective action of a gas bubble clinging to the edge of the " plateau " as indicated in Fig. 1. The height of the hill, therefore, gave a measure of the depth of metal removed in the electrolytic polishing process.

Such estimations of surface level, however, are limited by the depth of focus of the microscope and

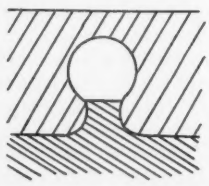

Fig. 1—Hill formation formed during the electrolytic polishing process by protective action of a gas bubble clinging to the edge of a plateau

this cannot be less than approximately 0·5μ. It would therefore be impracticable to measure variations in surface level of less than a few microns by this method, since the microstructure of the specimen would clearly be lost in the process of creating such great variations in surface level.

A device used by the engineer for the measurement of surface levels is the surface-finish recorder. This may take a number of forms, but is essentially a mechanism for traversing a probe across the surface under examination, and for measuring and recording the vertical displacements which the character of the surface imparts to the probe. Such recorders are sensitive to a millionth of an inch ($2{\cdot}5 \times 10^{-6}$ cm),

but are limited by the ability of the probe to penetrate the fine structure of the surface. The probes are usually diamond tipped; the radius of the end is approximately $\frac{1}{10000}$ in (0·00025 cm), and the two flanks running up to the tip are inclined to each other at 90°. Consequently the contour of abrupt variations in surface level cannot be faithfully recorded, although the change in level itself will be correctly rendered.

The electron microscope has been used in the determination of surface contours by analysis of stereoscopic pairs of electron micrographs from silica replicas[4] and also by qualitative analysis of electron micrographs from plastic-film replicas as previously pointed out (*see* p. 2). Such work, however, is relatively laborious, since replicas have to be made from the original specimens, and the final analysis must be made on the basis of the recorded electron micrographs, as the visual images seen on the fluorescent screen of the electron microscope are inadequate for the purpose.

Interferometry is an extensively used and powerful tool for the assessment of the geometric character of surfaces. The simple use of interference fringes permits assessments of surface level to within a fraction of a light wavelength, while the use of very narrow fringes from highly reflecting surfaces and reference plates greatly increases the power of the method.[5]

The interference microscope[6] presents an enlarged image of the object under examination with a superimposed pattern of interference fringes whose shape indicates the character of the surface of the specimen and effectively maps out a whole series of contour lines on homogeneous specimens.

In principle these interferometric methods work by comparing the phase of the light reflected from a particular part of the specimen with that reflected

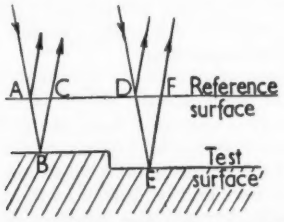

Fig. 2—Section through a specimen in which an abrupt step appears

from a plane surface which has either been placed nearly in contact with the specimen or has been imaged there.

These changes in phase are dependent on a number of factors which may be made clearer by reference to Fig. 2. This shows a section through a specimen in which an abrupt step appears. Above the specimen is the plane-reference surface. The light passes down through the semi-reflecting reference surface and is reflected from the specimen at B. The light reflected from A will be out of phase with that passing up through C by an amount depending upon the optical path lengths AB plus BC, and upon the phase changes occurring at the reflections at A and at B, and the position of the fringes crossing the upper step on the

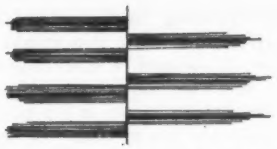

Fig. 3—Interference fringes likely to result from an arrangement such as that shown in Fig. 2

specimen will be dependent upon the total difference in phase arising from these various components. Similarly, light from the same source passing down through D to the lower step will lead to two beams passing up from D and F, respectively, which will be out of phase by an amount depending upon the optical-path lengths, DE plus EF, and upon the phase changes occurring at the reflections at D and at E.

The interference fringes which could result from such an arrangement are shown in Fig. 3. The displacement between the two fringe systems will depend upon the difference between the total phase differences arising in the ABC system and the total phase differences arising in the DEF system. If the test specimen is homogeneous, the phase changes occurring at the reflections at B and E will be identical, as will those at A and D, so that the displacement between the two fringe systems will then depend only upon the difference between the optical path lengths AB plus BC and DE plus EF and can therefore be related to the height of the step.

If, however, the step corresponds to the change from one material to another as may happen in metallurgy, the phase changes at B and E may differ from one another. The displacement between the two fringe systems will then depend not only on the height of the step but also upon the nature of the two materials at whose mutual boundary the step occurs.

From the metallurgical point of view, the most attractive of the methods so far discussed for assessing the surface character of a specimen is the interference microscope, as it presents a magnified image of the specimen upon which can be superimposed, at will, a pattern of interference fringes giving an indication of the surface character. It will be realized, however, that while the interpretation of the fringes is not difficult (ignoring for the moment the question of phase changes at reflection in non-homogeneous specimens) it does require a conscious effort on the part of the operator.

METHOD OF PHASE CONTRAST FOR THE DETECTION AND EXAMINATION OF PHASE CHANGES IN OPTICAL SYSTEMS

Optical systems are dependent finally upon a receptor system, such as a human eye or a photographic plate, which is sensitive only to variations in intensity within the image and insensitive to variations in phase. This may be illustrated by considering the case of a thin slip of glass viewed against a bright background. The light passing through the slip will be retarded with respect to the light from the background, because the refractive index of the glass is higher than that of the displaced air, but the phase

difference corresponding to this retardation will not render the slip visible. The slip would in fact only become visible on account of disturbances arising at its perimeter, or on account of reflection losses at its surfaces, or absorption losses in its body, that is in respect of changes in the intensity of the light.

Zernike's method of phase contrast[7] is a device whereby such invisible variations in phase in a wavefront can be converted into proportional variations in intensity in an image of that wavefront and so made visible to the eye and capable of being recorded on a photographic plate.

Referring back to Fig. 2, it is possible by this method of phase contrast to convert the phase changes in light reflected from a homogeneous specimen, and arising from variations in its surface level, into proportional changes in intensity so that, for example, the two levels shown in the figure would be rendered as two areas of different brightness in the image of the specimen. The geometric character of the surface of a homogeneous specimen is then assessed in terms of the brightness of its various parts, and this clearly calls for no great conscious effort on the part of the observer, for example, bright parts would be "heights" and dark parts "depths" and intermediate brightness would correspond to intermediate levels.

This provides an attractive alternative method for the assessment of surface levels and is in fact the basis of the phase-contrast incident-light microscope described in this paper. To understand the way in which it works it is perhaps easiest first to consider the means by which phase-contrast effects are obtained and to consider also the phase-contrast microscope for transmitted light which is already well established in the biological field.

For this purpose, reference may be made to many papers on phase-contrast microscopy which fully describe the theory and practice of the method as applied to transmission microscopes. It will suffice here simply to point out the physical differences between normal and phase-contrast transmission microscopes.

One difference is in the form of the illuminating beam. In the normal transmission microscope this is a solid cone of light which fills the aperture of the objective lens, whereas for phase-contrast microscopy the beam is limited, by means of an annular aperture in the illuminating system, to the form of a hollow cone.

A second difference is in the form of the objective lens. The special phase-contrast objective has a glass plate or some similar device placed in its back-focal plane. This carries an annular ring through which passes the light from the hollow cone. When a specimen is introduced into the beam, part of the light is diffracted away from the hollow cone and passes through areas of the special plate other than the annular ring. The ring may therefore be used to introduce phase or intensity differences between the direct and the diffracted light, and in the Cooke phase-contrast objective used in the present work the annular ring advanced the phase of the direct light relative to the diffracted light by 90°, that is by a quarter of a wavelength. It also reduced, to some extent, the intensity of the light passing through it.

It is this relative change of phase which gives rise to the phase-contrast effect by which small phase changes occurring in the object are interpreted as intensity changes in the image of that object.

APPLICATION OF THE PHASE-CONTRAST METHOD TO INCIDENT-LIGHT METALLURGICAL MICROSCOPY

In order to achieve phase-contrast effects in the microscopy of metals, it is necessary to have an optical system which will ensure that the direct light leaving any particular part of the specimen shall pass through the phase-change device in the objective lens while diffracted light from that point passes through unimpeded, as suggested in Fig. 4, which shows an axial section through a metal specimen and a schematic phase-contrast objective with an annular phase-change ring. It is desirable also that the light passing to the specimen shall go through the objective lens, thereby eliminating the need for semi-reflecting plates between the objective lens and the surface of the specimen by which light can be introduced. Such plates would in fact be impracticable in the case of high-power objectives which approach very closely to the specimen.

Now metallurgical specimens are commonly flat and behave as quite good mirrors even when etched sufficiently to bring up detail. If such a specimen is set up in a metallurgical microscope with one of the phase-contrast objectives intended for transmission work, it will be found that an image of the phase-change ring will be formed in the same plane as the ring itself by the combined action of the objective lens and the specimen, which acts as a mirror. This follows from the fact that the phase-change ring lies in the back-focal plane of the objective lens. The image of the ring will be of the same size as the ring itself and the two may be made to coincide by suitable orientation of the specimen.

If light is sent down to the specimen through the radial width of the ring only, all the light, in the case of a perfect-mirror specimen, will return through that same area since the ring and its image are coincident. In the case of a normal metallurgical specimen showing fine detail there will be diffracted light also, which will come back through the whole aperture of the objective.

Such an arrangement, therefore, even using an objective designed for transmission work, provides the conditions necessary for phase-contrast microscopy with incident light, although it will be realized that objectives not specially designed for incident-light microscopy may suffer from troublesome back reflections, which would have been avoided by the computer of a metallurgical objective.

A PHASE-CONTRAST INCIDENT-LIGHT MICROSCOPE

Description

An experimental phase-contrast incident-light microscope has been set up on the basis of the principles developed previously. In constructing the experimental model little attention has been paid to the use

of components of the most favourable size and the layout has been adapted to suit components readily available. The design is based on such phase-contrast objectives as are as yet available commercially, and these, of necessity, are objectives designed for use on transmitted-light microscopes.

To secure rigidity of the whole structure the various components have been clamped down to a heavy surface plate. This is a highly desirable device, as the least relative movement of the specimen and the objective lens can lead to serious defects in the highly magnified image of the specimen. Similarly, there are other parts of the system in which fortuitous relative movement cannot be tolerated. These remarks apply with special force in the case of phase-contrast microscopy, as the illuminating system must now maintain a more critical alignment than is required in the case of normal microscopy.

Fig. 5 shows in diagrammatic form a section through the experimental microscope in a horizontal plane passing through the optical axes. The specimen (S) is mounted on a specially constructed tilting stage so that the direction in which it reflects light is brought under control. The stage is also fitted with coarse and fine focusing adjustments, together with lateral adjustments permitting "scanning" of the specimen. The phase-contrast objective lens (O) is mounted rigidly in a member attached to the main frame of the microscope. Apart from the tilting stage, the apparatus so far described is in fact a normal metallurgical microscope which has been clamped down to the bedplate with its optical axis horizontal.

Immediately behind the objective lens is placed the beam splitter (B). This is mounted on the normal microscope body and consists of a glass plate about 5 mm thick, optically worked and coated with a film of zinc sulphide on the face nearer to the objective lens. This replaces the normal splitter consisting of a plain glass slip and has a relatively high luminous efficiency. The reflection factor is approximately 0·35 and the transmission factor is approximately 0·65, so that its efficiency in a system involving one transmission and one reflection is $0{\cdot}35 \times 0{\cdot}65$, which is to be compared with $0{\cdot}04 \times 0{\cdot}96$ for a plain glass splitter when only one face is allowed to contribute to the reflected beam. The use of the specially coated beam splitter may therefore be expected to increase the image brightness by a factor of approximately 6.

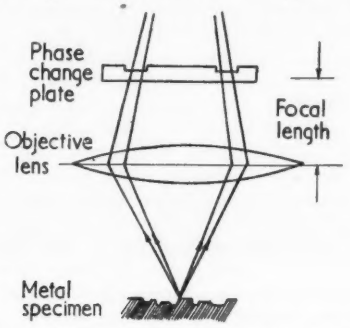

Fig. 4—Axial section of a phase-contrast objective, with an annular phase-change ring and metal specimen

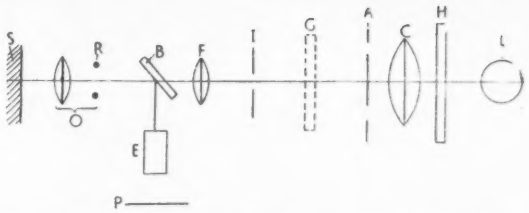

Fig. 5—Horizontal section of phase-contrast incident-light microscope

The remainder of the illuminating system, comprising the components F, I, A, C, H, and L, is set up on an optical bench securely clamped to the common bedplate. The iris diaphragm (I) and field lens (F) are so placed that an image of the iris diaphragm is produced by the joint action of field lens and objective lens on the surface of the specimen when this is in the position required for focus of the microscope.

An aperture (A), in the form of a clear annular area on an opaque ground, is so placed with respect to the field lens (F), that an image of the annulus is formed in the same plane as the phase-change ring (R) incorporated in the phase-contrast objective.

A condenser lens (C) is placed immediately behind the annular aperture (A) together with a heat-absorbing filter (H). The light source (L) is a mercury arc lamp, constituting a compact white-light source, so placed that an image of the arc is formed by the condenser lens (C) on the iris diaphragm (I).

A green colour filter (G) can be inserted in the illuminating beam at will so that advantage may be taken of the improved performance of the objective on a restricted waveband. It would be better from the optical point of view to place the colour filter on the condenser side of the annular diaphragm (A), but this would result in overheating and damage to most filters. It is therefore placed between the annular diaphragm (A) and the iris diaphragm (I) in a guide which ensures that it is always set at the same angle to the light beam. If this precaution were not taken, the image of the annular diaphragm (A), formed by the field lens (F), would be subject to slight lateral displacements dependent on the orientation taken up by the filter (G) and such random displacements could not be tolerated.

On returning from the specimen the light beam undergoes reflection at the beam splitter and the image of the specimen is viewed through an eyepiece (E). Alternatively the image is projected by the eyepiece on to a photographic plate (P) for recording purposes. The eyepiece (E) and associated camera are each firmly anchored to the common bedplate.

It will be seen that the positions of the illuminating and viewing systems have been reversed as compared with the usual metallurgical microscope. This is not an essential change but is connected with the particular beam splitter (B) used in the present experimental microscope.

The ideal beam splitter would be an infinitely thin pellicule transmitting 50% of the light incident upon it and reflecting 50%. Practical beam splitters, however, have a finite thickness and in the present application this leads to the formation of more than

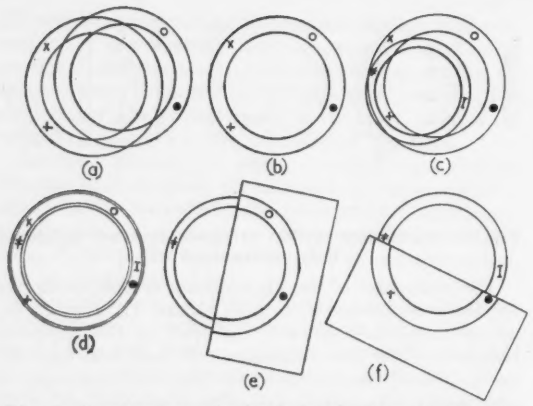

Fig. 6—Images seen in back focal plane of objective lens during alignment procedure

one image of the annular diaphragm (A) in the plane of the phase-change ring (R), on account of inter-reflections between the two faces of the beam splitter. Since the beam splitter is inclined to the beam, these multiple images are separated from one another and the degree of separation is dependent on the thickness of the splitter, being greatest in the case of a thick plate. In the present application it is important that only one image of the annular diaphragm (A) be operative. A thick beam splitter is therefore used and images other than the first are absorbed by a black mask placed around the back lens of the objective. Similarly, the beam splitter reflects more than one beam into the eyepiece system, but the lateral displacements of such beams as arise from inter-reflections are great enough to lead to their being absorbed on apertures in the eyepiece system so that only the image formed by the once-reflected beam is seen by the observer.

It would be unwise to form the magnified image of the specimen by transmission through the thick beam splitter as serious distortion would arise. Therefore, the device of forming the magnified image of the specimen by reflection at the front face of the beam splitter is adopted, so that the thickness of the latter is immaterial. The image of the annular diaphragm (A) has, of course, now to be formed by transmission through the thick plate, but the requirements are much less critical in this case and such distortion of the annular image as may arise is unimportant.

Alignment of the Microscope

The specimen is mounted on plasticine on a glass slide and its surface is made parallel with the slide in the usual manner. It is then mounted on the stage of the microscope and brought into focus. General illumination can be provided for this process by placing an opal lamp on the axis of the system between the iris diaphragm (I) and the annular diaphragm (A).

The eyepiece is then removed and an auxiliary microscope substituted and so adjusted that the phase-change ring (R) in the back focal plane of the objective lens comes into focus. A second ring of the same size will be seen simultaneously, being the image of the phase-change ring formed by the objective lens with the specimen acting as a mirror. The field of view in the auxiliary microscope at this time is depicted in Fig. 6 (*a*). Identifying marks have been added to the various rings so that their positions may be identified in subsequent Figures.

The first step in the alignment procedure is to make the phase-change ring and its image coincident by manipulation of the tilting controls on the specimen stage. Figure 6 (*b*) shows the field of view after this adjustment has been completed. This adjustment may result in an alteration of the distance between the specimen and the objective lens with resultant restriction of the illumination to a small part of the field only. Full field illumination may be restored by manipulation of the focusing controls on the specimen stage.

The opal lamp is removed from the system and an image of the annular diaphragm (A) is then seen in the field of the auxiliary microscope in addition to the superimposed images of the phase-change ring. The image of the annular diaphragm (A) is brought into sharp focus by axial adjustment of the field lens (F) and the field of view now appears as shown in Fig. 6 (*c*).

The final requirement in the alignment is that the image of the annular diaphragm (A) shall be concentric with the superimposed images of the phase-change ring and its own radial width shall lie wholly and symmetrically within the radial width of the phase-change ring as indicated in Fig. 6 (*d*).

The rings are made concentric by lateral adjustment of the annular diaphragm (A), but any discrepancy in size must be corrected by changing the magnification due to the field lens (F). This will involve changes in the axial position of the lens (F), with corresponding axial movement of the condenser system ACHL as a whole to bring the image of the annular diaphragm (A) back into focus in the plane of the phase-change ring (R).

The conditions for good visibility of the phase-change ring (R) and its image are different from those required for viewing the image of the annular diaphragm (A), and the previously mentioned alignment procedure is made easier if the following devices are adopted :

The brightness of the image of the annular diaphragm (A) is reduced to a comfortable level by introducing diffusing or absorbing screens between the diaphragm (A) and the light source (L). A piece of white card is then placed as nearly as possible in the plane of the annular diaphragm (A) and its edge is allowed to overlap the annulus. The white card is strongly illuminated on the side facing the field lens (F). Part of the phase-change ring will be clearly seen in the field of the auxiliary microscope against a white ground formed by the card, and the image of the annular diaphragm (A) will be seen in the remainder of the field as depicted in Fig. 6 (*e*) and (*f*). Movement of the card across the annulus in various directions then readily shows whether the image of the annular diaphragm (A) lies wholly and symmetrically within the radial width of the images of the phase-change ring (R). The auxiliary microscope is removed and the specimen brought into focus in

Fig. 7—Normal photomicrograph

Fig. 10—Normal photomicrograph

Fig. 8—Electron micrograph; plastic-film replica

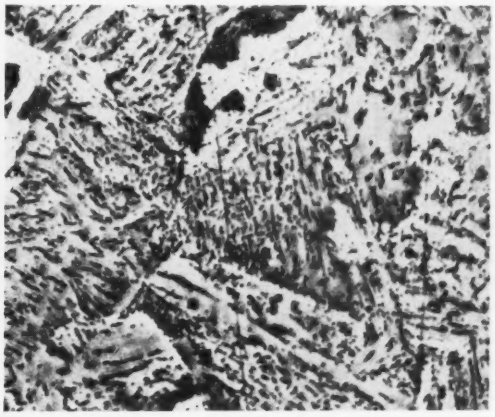

Fig. 11—Phase-contrast photomicrograph

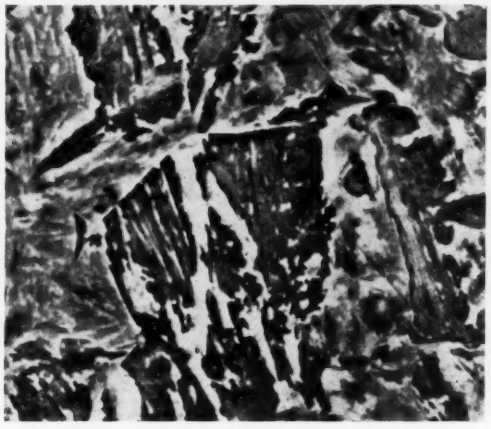

Fig. 9—Phase-contrast photomicrograph

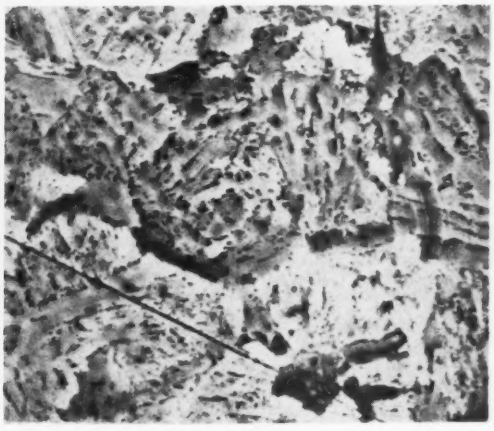

Fig. 12—Phase-contrast photomicrograph from aluminized specimen

Figs. 7 to 9—Nickel-chromium steel: " Intermediate transformation products " All × 1500

Figs. 10 to 12—Manganese-molybdenum alloy steel: tempered martensite All × 1500

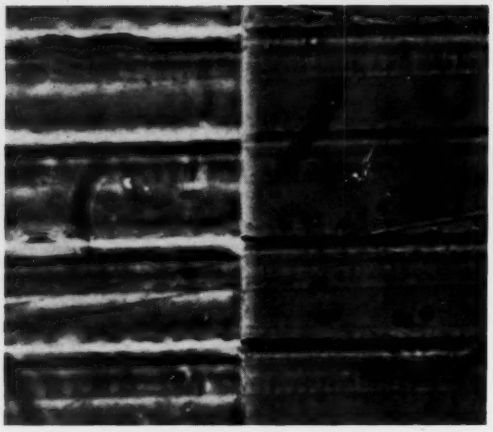

Fig. 13—Grating on steel, 2400 lines per in. × 1500

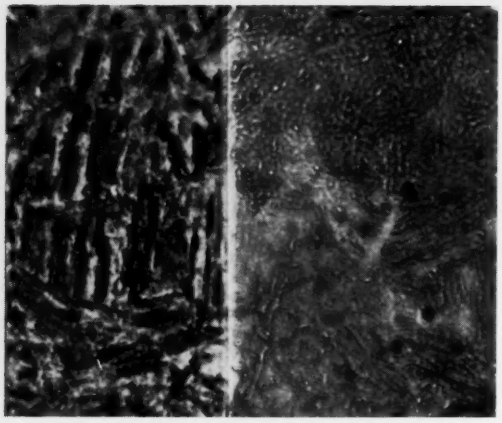

Fig. 14—Nickel – chromium steel: martensitic structure × 1500

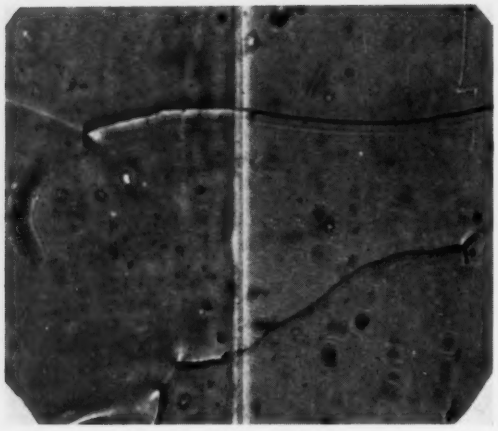

Fig. 15—Bismuth in copper: intercrystalline films × 1500

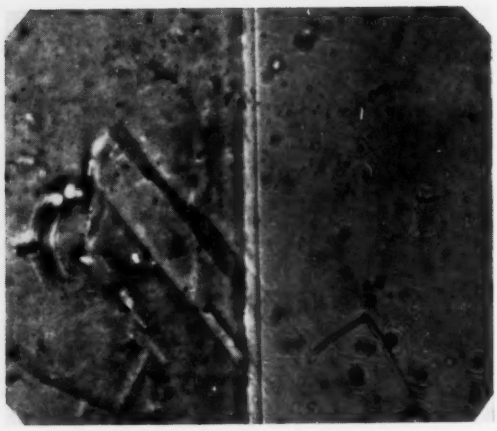

Fig. 16—Copper: twinning × 1500

Figs. 13 to 17—Photomicrographs from comparative microscope in which the left-hand and right-hand parts of the fields are phase-contrast photomicrographs and normal photomicrographs, respectively

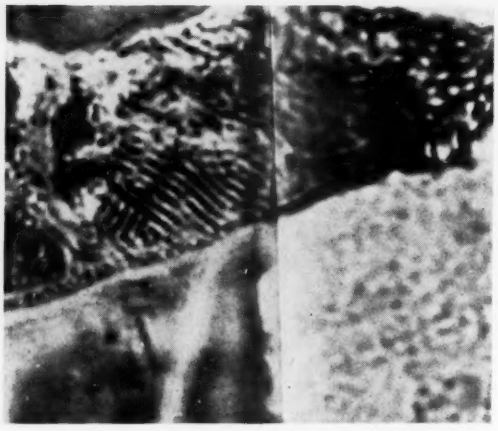

Fig. 17—Pearlite, showing lamellar structure × 4500

the eyepiece (E) by adjustment of the focusing controls on the specimen stage. The axial position of the iris diaphragm (I) is adjusted until its edge, as seen in the field of view of the microscope, is sharply focused, and its lateral position is adjusted until its image is concentric with the well-focused centre portion of the image of the specimen. The size of the iris diaphragm (I) can then be adjusted to restrict the field of view to that part of the specimen which the objective lens is capable of bringing into sharp focus.

It should be pointed out that once the illuminating system has been aligned in this manner there should be no need to make further adjustments save as a result of accident or in the event of changing to an objective lens of a different power. There is no reason why the image of the annular diaphragm (A) should not stay permanently in focus and in register with the phase-change ring (R). A possible variable quantity affecting the general alignment, but not that of the illuminating system, is the orientation of the surface of specimen (S).

If the phase-change ring (R) in the objective lens is slightly eccentric with respect to the optical axis, coincidence of the phase-change ring and its image can only be achieved by tilting the specimen so that its surface is no longer at right angles to the optical axis. Succeeding specimens would then have to be orientated in the same way and this can be done in a number of ways. The specimen can be mounted normally and then placed on an appropriately tilted stage on the microscope, or the specimen can be mounted with the correct degree and direction of tilt and used on a normal microscope stage. Of these, the first method is preferred as it is then easier to maintain the correct direction of tilt with respect to the objective lens.

The best solution, of course, is to make phase-contrast objectives with exactly centred phase-change rings and to use these on microscopes in which the specimen stage is truly at right angles to the optical axis of the objective. If flat specimens are then carefully mounted parallel with the microscope stage the need for adjustment of the orientation of the specimen when on the microscope disappears.

Difficulties could still arise due to lack of flatness of specimens such as may be encountered in the case of electrolytically polished metals. Care should then be taken that the phase-change ring and its image are in fact coincident after any lateral movement of the specimen.

Method of Using the Microscope

In the present work, specimens have been mounted on glass slips by means of plasticine in such a way that the surface of the specimen is parallel with the bottom of the slip. The device used for this levelling is that described by Rosenhain[8] which is sensitive to changes of a twentieth of a degree. The specimen has then been mounted on the stage of the experimental microscope which had already been set to the correct tilt during the alignment carried out earlier.

The present work is concerned with high magnifications only and a 1·8-mm oil-immersion Cooke phase-contrast objective, kindly loaned by the makers, Messrs. Cooke, Troughton and Simms, has been used throughout. The microscope has been focused after applying immersion oil and at this stage it has been usual to check the alignment of the system by viewing the various ring images in the back-focal plane of the objective lens by means of the auxiliary microscope in the manner described in the alignment procedure. The eyepiece has then been restored and the highly magnified image of the specimen examined visually or recorded photographically.

It will be seen from this section that once the phase-contrast incident-light microscope has been aligned the method of using it differs in no particular from that applicable to a normal metallurgical microscope when normal flat specimens are used. The precaution of checking the alignment is taken simply to guard against misalignment due to accident or to the use of specimens which are either not flat or incorrectly mounted.

Metallography with the Phase-Contrast Incident-Light Microscope

To determine the value of the phase-contrast incident-light microscope in metallography, it has been used in the examination of a number of metal specimens presenting a variety of problems.

The first specimen is the nickel–chromium steel mentioned on p. 2, and of which Figs. 7 and 8 are a normal photomicrograph and an electron micrograph from a plastic film replica, respectively.

Figure 9 is a phase-contrast photomicrograph prepared on the instrument described previously. The depth of etching of the specimen is the same as that used in preparing the other micrographs. The degree of contrast available is now very high and it has had to be reduced by appropriate photographic treatment in subsequent stages. It is believed that as attention is directed to the question of the most desirable contrast levels, better micrographs will be obtained. The level can be adjusted by control of etching or by appropriate photographic technique in the case of recorded micrographs.

There is a striking resemblance between the phase-contrast micrograph and the electron micrograph: each represents depressions and elevations on the specimens as dark and bright areas, respectively, in the micrograph. The advantage of high contrast between phases offered by the electron microscope now becomes available, therefore, on a light microscope, which permits direct vision and rapid scanning of the whole specimen. The high resolution associated with electron microscopy is lost, however.

The second specimen was an alloy steel showing a tempered martensite structure. The analysis of the steel was as follows:

Carbon ...	0·27%	Manganese	1·41%
Phosphorus	0·025%	Molybdenum	0·40%
Chromium	0·09%	Sulphur ...	0·021%
Silicon ...	0·24%	Nickel ...	0·05%

Figure 10 shows a normal photomicrograph of this specimen characterized by a uniformly bright background, with many black dots in which a semblance of order can be discerned on close inspection. Figure 11

shows a comparable phase-contrast photomicrograph. The whole picture appears much sharper and in addition the field becomes divided into various areas, each of a particular brightness, and in each of which the black dots are lined up in a direction peculiar to that area. There is a tendency to regard the black dots seen in the normal photomicrographs as " particles," but since they appear dark in the phase-contrast photomicrograph they are probably small pits. The uncertainty associated with that deduction is due to the fact mentioned earlier that the effects seen in the present phase-contrast photomicrograph are due not only to phase changes corresponding to variations in surface level, but also to phase changes occurring at reflection, and the latter depend upon the particular materials involved.

As a first attempt to eliminate this uncertainty, the present specimen was coated by evaporation *in vacuo*, with a film of aluminium possibly 1000 Å thick. As most of the reflected light would then come from the aluminium the phase change at reflection might be expected to be the same in all areas so that phase-contrast photomicrographs should then indicate variations in surface level only.

Figure 12 is a phase-contrast photomicrograph prepared in this way. Since the microstructure has not been seriously impaired it is probable that the upper surface of the aluminium film is reproducing the geometric structure of the surface on which it is formed. The dots still appear as black dots, so that these features must be due to minute pits on the surface of the specimen and not to " particles."

The third specimen was of almost pure copper which had been electrolytically polished but had not been deliberately etched. On examination in the normal metallurgical microscope it appeared almost characterless apart from occasional inclusions. The phase-contrast microscope on the other hand showed many crystal boundaries and revealed twinning quite clearly.

A COMPARATIVE MICROSCOPE FOR PHASE-CONTRAST OR NORMAL MICROSCOPY OF A SINGLE FIELD

Description

Emphasis has been laid in this paper on the desirability of making inter-comparisons between micrographs prepared from the metallurgical specimens by a variety of methods. Each type of micrograph has its own difficulties of interpretation, not excluding the normal photomicrograph, and evidence presented by one type of micrograph will sometimes reinforce evidence from another.

Such comparisons are better conducted with micrographs showing exactly the same field as seen through the agency of the various methods, and this has led to the development of a comparative microscope on which a rapid visual examination of any field, or feature within that field, can be made under phase-contrast conditions or those of normal microscopy, at will, by simple movement of a cross slide.

The field of view in the comparative microscope is divided into two parts by a vertical line. The part of the specimen to one side of the line is seen under the conditions of normal microscopy (full cone illumination in the present instance) and the part of the specimen to the other side of the line is seen under phase-contrast conditions. It is then easy to see if one method has any advantage over the other for the particular specimen examined. The dividing line can be moved across the field so that any feature in the field may be examined by the two methods in quick succession, so facilitating an appraisal of the differences.

To achieve this effect it is necessary to provide simultaneously two types of illumination of the specimen. Firstly, a solid cone of light for ordinary microscopy, and secondly, a hollow cone of light which is made to pass through the phase-change ring, for phase-contrast microscopy.

In place of the annular diaphragm (A), in Fig. 5, is substituted the new condenser stop indicated in Fig. 18. This contains an annular area (B) of exactly the same size as the original annular diaphragm (A). All the light passing through the new annulus, however, is polarized vertically by a film of " Polaroid " material. Concentric with the annulus is an inner circular area (C) through which passes light horizontally polarized. The remainder of the diaphragm, that is the area between the annulus and the circle and also the area outside the annulus, is opaque.

The cross slide is mounted as close as possible to the iris diaphragm (I) and carries two pieces of Polaroid film side by side and in very close contact, as indicated in Fig. 19. One piece polarizes light passing through it in a vertical plane and the other piece polarizes in a horizontal plane.

The cross slide is moved axially until the dividing line between the two pieces of Polaroid film is clearly focused on the surface of the specimen so that the part of the specimen to one side of the dividing line receives light which has come through part C of the cross slide, and therefore from the circular centre part C of the condenser diaphragm system. Similarly, the part of the specimen on the other side of the dividing line receives light which has come from the annular area B of the condenser diaphragm system *via* part B of the cross slide.

Fig. 18—New condenser stop as used in place of annular diaphragm (A) shown in Fig. 5

The parts of the specimen lying on either side of the dividing line are therefore so illuminated as to give rise to normal and phase-contrast images, respectively. When the cross slide is moved laterally in the direction of the arrow, in Fig. 19, the dividing line passes across the field of view of the microscope in a direction which increases the area of the specimen seen under phase-contrast conditions. If the part B of the cross slide completely covers the aperture of

the associated iris diaphragm the whole field of view is seen under phase-contrast conditions.

The specimen can therefore be examined with either normal or phase-contrast conditions covering the whole field of view, or under split-field conditions permitting ready assessment of the more favourable system for the particular specimen examined.

Examples of Use of the Comparative Microscope

In calibrating the magnification of the microscope, micrographs were prepared from a ruling made with a diamond on a hardened-and-lapped steel disc by means of a dividing engine. There were 2400 lines to the inch (94 to the mm). Figure 13 shows the photomicrograph prepared on the comparative phase-contrast microscope. The foreign bodies are debris thrown up by the diamond tool. The two parts of the field are very dissimilar. The normal photomicrograph appears sharper, but the phase-contrast micrograph, in which heights on the specimen appear bright, indicates that the intense dark lines seen in a normal microscope are in fact pronounced ridges on the surface and not the grooves due to the ruling tool. The latter being depths appear dark in the phase-contrast photomicrograph (as do two adventitious scratches which cross the field), but appear (somewhat surprisingly) as bright lines in the normal photomicrograph. Similarly, evidence is provided concerning the character of many other markings seen clearly in the normal photomicrograph, but incapable of interpretation from that picture in terms of surface form.

Figure 14 shows a comparative normal/phase-contrast photomicrograph from the nickel–chromium steel mentioned on pp. 2 and 7, but at an earlier stage in the heat-treatment when the structure was almost entirely martensitic. The specimen had been only very lightly etched with a view to showing up the intermediate transformation products, if already separating out, but without much attack on the martensite. While the normal photomicrograph might conceivably be interpreted as having the acicular

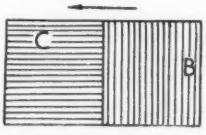

Fig. 19—Cross slide carrying two pieces of Polaroid film in close contact

structure of martensite, this structure is very much more apparent in the associated phase-contrast photomicrograph. Examinations of such structures should therefore be greatly facilitated.

Figure 15 shows further a comparative photomicrograph from a specimen of wrought non-arsenical phosphorus deoxidized copper containing a small quantity of bismuth. This specimen had already been examined by means of the electron microscope[3] through the agency of plastic replica films and the general correspondence between the phase-contrast photomicrograph and the earlier electron micrographs is noteworthy. In Fig. 15 the exposed edges of the intercrystalline film appear merely as black lines, whereas the phase-contrast photomicrograph shows a duplex structure suggesting a ridge bordered by a depression (bright line bordered by a dark line) which was a possible structure put forward as an interpretation of the electron micrograph. Figure 16 is from another specimen in this series which clearly shows the superior behaviour of the present instrument in the observation of crystal boundaries, in particular of twinning.

Whereas the twins in the normal photomicrograph are indicated by a rather diffuse dark line at the crystal boundary, the phase-contrast photomicrograph shows twins as areas of different brightness and the dividing line between these areas is quite sharp. The picture, therefore, not only gives an impression of improved contrast but also of a real gain in resolution.

An instrumental difficulty arising from the fact that the Polaroid films in the cross slide are focused on the object, is that any extraneous matter accidentally trapped there appears as a blemish in the micrographs. Blemishes can be seen in the micrographs showing the split field and most are due to this trouble. Others arise from the use of a beam splitter which was unnecessarily large, and therefore had to be placed some distance away from the back lens of the objective, with the result that the extraneous matter on its surface appears as a diffuse mark in the micrograph ; both, of course, are avoidable defects.

RESOLVING POWER

The suggestion of improved resolution had arisen earlier in the case of the tempered martensite specimen (*see* Figs. 10, 11, and 12). A direct test of relative resolving powers was therefore proposed in which a steel specimen would be used which was considered to contain fine pearlite, although careful examination on a normal metallurgical microscope revealed only occasional areas which could be seen to contain a lamellar structure.

Visual examination of this specimen on the phase-contrast microscope showed perfectly clear lamellar structures immediately in almost all fields of view. Figure 17 shows a comparative photomicrograph of one area. In the part of the grain seen under phase-contrast conditions the lamellar structure is obvious, but the remainder of the grain seen under normal conditions shows only a diffuse pattern which is not a certain indication of pearlite.*

This appears at first to be a clear indication of greatly improved resolving power, but a large part of the effect is believed to be directly attributable to the great depth sensitivity of the phase-contrast method. This has the effect of making the exposed edges of the lamellae visible in respect of their small but now appreciable height, and the microscope then needs only moderate resolving power to maintain their images as separate entities. It is suggested that the

* It should be pointed out that the aperture available for use in normal microscopy is restricted to a little less than that used in the hollow-cone illumination for phase-contrast microscopy in the present comparative microscope, but confirmation of the rarity of obviously pearlitic areas is given by the earlier observations on normal metallurgical microscopes which were operated at optimum aperture.

normal metallurgical microscope fails to make the lamellae visible merely by having inadequate powers of contrasting them with the background so that its adequate resolving power is not called into play. This may not, however, be quite the whole story and the question of resolving power deserves further attention with specimens showing finer spacings.

CONCLUSIONS

The phase-contrast incident-light microscope is regarded as the most convenient instrument for the assessment of surface levels and associated factors for metallurgical purposes, in that information on these points is impressed on an enlarged image of the specimen in a form which is easily assimilated.

It is likely to be particularly useful as a pilot instrument in electron metallography, as it gives images very similar to those obtained from plastic film replicas without their high resolution, but with the advantages of direct vision and unrestricted scanning.

Fundamental work is required to assess the relative importance of the characteristic phase changes involved in the reflection of light from various materials. The present instrument provides micrographs dependent upon these phase changes in addition to the variations in surface level in the specimen.

If the phase changes at reflection prove to be a major factor in this method of working, it may be desirable to separate the two effects, as they may each be of more service in metallurgy individually than in combination.

Indirect evidence, provided by a limited number of comparisons between phase-contrast photomicrographs and electron micrographs of plastic replicas from the same specimens, suggests that the phase-change-at-reflection effect may be relatively unimportant.

The resolving power of the phase-contrast microscope, as determined by its ability to provide clearly separated images of closely spaced pearlitic lamellae, is high and further attention should be given to its assessment and comparison with theoretical expectations.

It is possible to adapt existing metallurgical microscopes to the phase-contrast method of working. A Vickers projection microscope has been so adapted by using the 1·8 mm phase-contrast objective made by Messrs. Cooke, Troughton and Simms. The following alterations have to be made to the apparatus also :

The normal beam splitter is replaced by one which has a high-reflectivity coating on one face and a low-reflectivity coating (bloom) on the other ; or, preferably, by a suitable pellicule

An annular condenser stop of carefully determined size is used in front of the condenser iris

Two-way lateral adjustments are provided for the annular stop

A field lens is used of such a focal length that the annular condenser stop is focused in the back-focal plane of the objective.

Care is taken to see that the objective lens is used at the correct tube length.

OTHER WORK ON PHASE-CONTRAST INCIDENT-LIGHT MICROSCOPY

A short note on this work has already been published[9] and it has been learned that experiments in phase-contrast incident-light microscopy have been made independently in France[10] and in the United States of America,[11] but in neither case was it reported that the possibilities of the method had been explored in the field of microscopical metallography. A number of photomicrographs of metal specimens were included in a recent publication.[12] A short phase-contrast bibliography is given at the end of the paper.

Acknowledgments

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Corrosion-Fatigue of Steel under Asymmetric Stress in Sea Water

By A. J. Gould, M.I.C.E., M.I.N.A.

SYNOPSIS

The severity of corrosion-fatigue in sea water under reversed stress with superimposed tensile stress depends on the stress-range, but is found to be almost independent of the mean stress of a cycle, provided that this is not excessive. The result was obtained on polished specimens, scale-covered specimens, and specimens descaled by pickling. The endurance as measured on a push-pull machine is roughly five times as great as that measured on a rotating-beam machine for the same materials and stresses. In well-aerated sea water, the test-piece breaks at its most slender section. In the absence of aeration, fracture usually occurs about 1 cm below the water-line, even though the stress here may not be maximal.

Introduction

The Nature of the Problem

THERE has been uncertainty concerning how far corrosion-fatigue is an important factor in determining the useful life of ships' plates. Whether an appreciable loss of strength can be caused depends upon :

The alternating stress system sustained (*i.e.*, the mean stress of a stress cycle, and the range of the superimposed reversed stress)

The frequency with which the alternations of stress are applied

The time during which this action continues (*i.e.* the useful life of the stressed plate).

Inevitably, the load-buoyancy reactions upon the hull will impose stresses in a ship's structure, even when the ship is at rest in still water. These stresses will be altered when the ship is in a sea-way, but their mean values can be seldom, or never, zero.

Unfortunately, little has been published upon the effects of corrosion-fatigue when the mean stress of the cycles is not zero. It can be anticipated with some confidence, that for a riveted ship's structure, after the ship has had time to ' breathe,' the mean stresses will be quite small even under the worst conditions ; but the state of things may be very different in the case of welded structural members, where, in certain places, residual tensile stresses will exist after welding. Fatigue stresses will be superposed upon these residual stresses, and the mean stress of a cycle, in a particular strength member, will approximate to that of the residual stress.

The corrosion-fatigue damage, at stress-ranges commonly met with in service, is usually attributed to the tensile half-cycle rather than the compressional half-cycle ; thus, to take a simple example, it might be expected that a tensile stress of 4 tons/sq.in. superposed upon a reversed stress of $\pm$ 8 tons/sq.in. would reduce the life of a plate in sea water to much the same extent as a reversed stress of $\pm$ 12 tons/sq. in. If so, the superimposition of this tension might reduce the life of the plate to about one third of what it would be otherwise. Residual stresses due to welding, however, must be expected to exceed 4 tons/sq. in. ; indeed, where the welding is conducted with the plates or bars under restraint, stresses near the yield may be expected.[1, 2]

Consequently, when the present research was started, considerable uncertainty still existed concerning the safety of welded ships in their later life. It is hoped that the new results obtained will be of assistance to those who have to settle the practical questions of ships' construction.

This report presents an account of an investigation, undertaken with the support of the Naval Construction Department of the Admiralty, into the properties of mild steel subjected to corrosion-fatigue in sea water at various values of mean stress, and superposed reversed stress.

The Plan of the Present Research

It was decided to measure the corrosion-fatigue lives of specimens immersed in sea water and subjected to stresses oscillating about various tensional mean values, including zero. In the main experiments the sea water was to be well aerated by the passage of small bubbles, so as to simulate service conditions. The specimens were to be in different conditions :

Free from visible oxide, with a good polished surface

Covered, completely or incompletely, with oxide scale

Covered with oxide scale, but descaled in a pickling bath without inhibitor

Covered with oxide scale, except over a narrow longitudinal band where the metal is bared.

EXPERIMENTAL TECHNIQUE

Materials

The specimens were machined from mild steel bars, the analysis of which was as follows :

	Chemical Composition, %							
C	Si	S	P	Mn	Ni	Cr	Mo	Cu
0·16	0·06	0·053	0·038	0·58	0·05	0·03	...	0·05

The following physical properties were found by actual test :

Tensile yield stress	20·2 tons/sq.in.
Ultimate tensile stress	28·0 tons/sq.in.
Elongation on 2 in	37%
Reduction in area	65%
Fatigue limit (in push-pull)	13·3 tons/sq.in.
Ratio fatigue-limit/U.T.S.	0·48

For the study of test-piece surfaces, bare of oxide, and for those covered with thick oxide, the specimens

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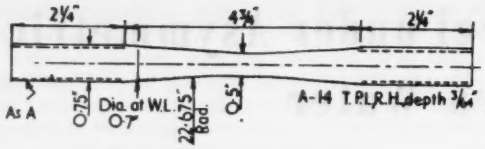

Fig. 1—Details of test-pieces

were finished with 0000 French emery paper, the final rubbing direction being circumferential. Those covered with thick oxide were then heated to 850° C in an electric muffle-furnace, held at that temperature for 1 hr and furnace-cooled. A special fatigue test was conducted upon this oxide-coated material, and it was established that the air-fatigue properties had not been altered by the reheating.

A number of the scale-covered specimens were pickled, so as to remove the oxide scale completely. The pickling bath contained 1 part of concentrated hydrochloric acid, and 19 parts of distilled water. These specimens were immersed, vertically, for 24 hr, then removed, washed in warm running water, and dried.

For the investigation of test-pieces covered with oxide, interrupted by a narrow longitudinal band of bare metal, scale-covered specimens were abraded longitudinally with 1F emery paper until bare metal was fully exposed to a width of 0·05 in. All specimens were successively degreased in benzene, carbon tetrachloride, and acetone, before heat-treatment was conducted, and again before being placed in the machine. The sea water used in these experiments was supplied by the Admiralty Metallurgical Laboratories, Emsworth.

Apparatus

Although rotating-beam fatigue machines are very cheap and compact, the stressing system which they impose is not representative of that sustained in a sea-way by the structural components of a ship. A rotating beam is only fully stressed at the skin : the stress intensity at any radial distance from the axis varies directly as the distance, and is zero at the axis itself. Again, at any point, the mean stress value is zero, so that only reversed stressing can be imposed. Finally, under corrosion-fatigue conditions, an e.m.f. may be set up between the tensional and compressional regions, which finds no counterpart in marine service.

Since a structural component of a ship has to sustain push-pull forces which, at any instant, are of nearly constant intensity over the whole of its cross-sectional area, and the actual stress system is "alternating" or "fluctuating" and probably never "reversed," it seemed desirable to use a push-pull electromagnetic machine. This type of apparatus is elaborate, and necessarily expensive.

By the kindness of Professor Wesley Austin, a 6-ton Haigh machine[3] was secured for this work. It is of the best type available for the purpose contemplated, and it can impose any type of push-pull loading up to its maximum range of 6 tons. In consequence, test-pieces with an unusually large diameter can be used. This is very desirable, because the closer the test-piece approaches the actual structure in sectional dimensions, the more nearly can the service behaviour of the structure be predicted from that of its model, the test-piece, in the laboratory.

For the manufacture of the large number of test-pieces needed, it was necessary to arrange for the easy, rapid, and precise, machining of a simple profile with no fillets. A generating linkwork directed by inclined, straight guide plates was designed, and fitted to a workshop lathe. The mechanism directed the lathe tool so that the test-piece was machined with a profile representing an arc of a circle. The operation was wholly automatic. Particulars of the test-pieces are shown in Fig. 1.

A test-piece was arranged in the Haigh machine as shown in Fig. 2. The surrounding, flask-shaped vessel which held the sea water was made of polyethylene, a tough material which is inert to most chemicals. The sea water was well aerated by shaking with air in a closed flask before it was poured into the polyethylene container, the water surface being near to the top of the test-piece. During an experiment, the sea water was aerated by a continuous stream of small air bubbles directed from a glass rubber-tube fixture as shown in Fig. 2. The bubbles did not impinge on the steel.

Experimental Method

After a test-piece had been inserted into the machine, the steady-stress value was adjusted and the machine was run-up until the desired reversed stress, and frequency, were obtained. The sea water was now poured into the container, and observations were taken of the counting mechanism and the time. The air stream was then adjusted and the machine left to itself, except for occasional inspection and adjustment. When a specimen broke, the machine stopped automatically, and the endurance of the test-

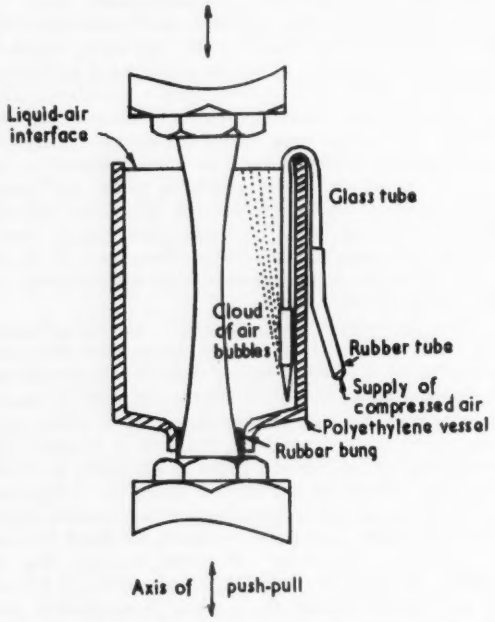

Fig. 2—Arrangement for the aerated corrosion of test-pieces

piece in cycles was indicated by the counting mechanism.

Since it was not possible to install the apparatus in a thermostated room, it was necessary to keep a record of the room temperature during each experiment. Although the temperature at the point of breakdown is probably very different from that of its surroundings, it was shown in an earlier research[4] that room temperature does affect the endurance. A thermograph was used to follow temperature fluctuation, its accuracy being checked by means of a maximum–minimum thermometer. A temperature correction was applied to each endurance so that values standardized to a temperature of 75° F could be plotted. The correction factor used, a 3·3% increase/decrease of endurance for each degree Fahrenheit of fall or rise of temperature, was based on the research just quoted, which was carried out on steel similar in quality and condition to that used in these new experiments. The corrected endurances fall fairly well on curves, whereas the uncorrected values showed a serious scatter.

Results

The mild-steel used has been studied in various conditions, under several systems of stressing action. On this material, the air-fatigue limit was ± 13·3 tons/sq. in. The values of superimposed tensile stress were always chosen so as to keep the resultant stress in the tensional half-cycle less than 13·3 ; actually the highest value adopted was 12 tons/sq. in. The investigation was carried out in steps as follows :

(*i*) Determination of the ordinary physical characteristics of the steel (given in Table I).

(*ii*) Determination of the air-fatigue limit of the steel ; results given in Table II and plotted in Fig. 3.

(*iii*) Determination in sea water of the corrosion-fatigue endurance of the steel, in various conditions, under push-pull stressing, at various values of the mean stress of cycle, and of the reversed stress superimposed. These results are given in Tables IV, V, VI, VII, and VIII, and plotted in Figs. 3 and 4.

Table I

TENSILE TESTS

Test No.	Yield Stress, tons/sq.in.	Ultimate Tensile Stress, tons/sq.in.	Reduction in Area, %	Elongation on 2 in., %
1	20·2	28·3	63	35
2	...	27·7	68	39

Table II

PUSH-PULL ENDURANCE TESTS IN AIR (2300 CYCLES/MIN.)

Test-pieces: Smeared with vaseline

Test	'Reversed' Stress Range, tons/sq. in.	Endurance, cycles × 10^4
1	±16·075	0·217
2	±16·075	0·200
3	±15·3	0·300
4	±14·5	0·942
5	±13·0	>2·960*
6	±12·0	>5·305*

* Unbroken

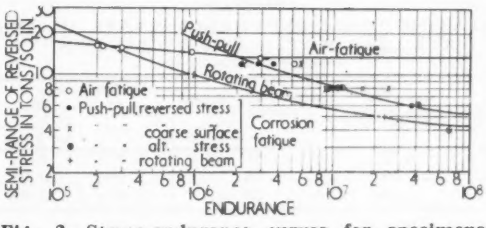

Fig. 3—Stress-endurance curves for specimens with ground surfaces

(*iv*) Determination in sea water of the corrosion-fatigue endurance of the steel, as polished and free from scale, at various values of the reversed stress in a rotating-beam machine. The results which are given in Table III and plotted in Fig. 3, are based on single determinations at each stress, but accord well with McAdam's values for steel of similar quality tested under similar conditions in sea water.

DISCUSSION

Interpretation of Results

The curves of Figs. 3 and 4 establish certain important facts :

(*a*) For the stress values used, the endurance values of the polished steel in sea water were about five times greater with push-pull stressing than with rotating-beam stressing of the same value. This is in accordance with the following theoretical reasoning :

In the case of a push-pull sample, all the anodic places are simultaneously exposed to yawning, although this occurs only during the tensional half-cycles. In the case of a rotating beam, only a fraction of the anodic places is correspondingly fully exposed at a given moment. It follows that the ratio of the anodic to cathodic area is diminished. Consequently, provided that the 'control' of the corrosion processes is partly cathodic, the currents flowing in the case of push-pull action will be of lower intensity than those flowing in rotating-beam action, thus producing a correspondingly slower rate of damage.

Most laboratory measurements have been conducted on rotating-beam machines, which (as it now appears) may predict much shorter working lives for many structures subjected to alternating stress than would actually be realized in service. It must be emphasized, however, that this behaviour may be expected only under conditions comparable with those prevailing in these experiments. In particular, the specimens were immersed in aerated sea water, whilst

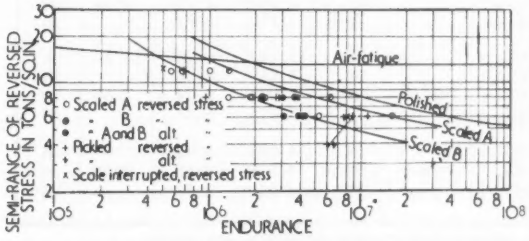

Fig. 4—Push-pull stress-endurance curves for specimens with scaled, and pickled, surfaces

Table III

ROTATING-BEAM ENDURANCE TESTS IN AERATED SEA WATER (1650 CYCLES/MIN.)
Test-pieces: Polished steel

Test	'Reversed' Stress Range, tons/sq. in.	Mean Temperature during Test, °F.	Endurance, cycles × 10^6	
			Actual	Corrected for 75° F.
1	±15	64	0·395	0·29
2	±10	65	1·294	0·97
3	± 5	70	27·868	23·90

Table IV

PUSH-PULL ENDURANCE TESTS IN AERATED SEA WATER (2300 CYCLES/MIN.)
Test-pieces: Polished steel

Test	Stress, tons/sq. in.	Mean Temperature during Test, °F.	Endurance, cycles × 10^6		
			Actual	Corrected for 75° F.	Average for 75° F.
C 5	0±12·0	76	3·555	3·67	2·90
C 9		75	2·837	2·84	
C15		74	2·249	2·18	
C 1	0±8·0	75	9·812	9·81	11·15
C 4		73	12·663*	11·85	
C 6		78	10·741	11·80	
C 7	4·0±8·0	78	8·421	9·27	10·65
C 8		72	11·948	10·86	
C10		80	10·173	11·83	
C11	0±6·0	81	31·159	37·40	37·40
C12	6·0±6·0	85	31·358	41·70	41·70
C13	8·0±4·0	75	71·018†	71·02	71·02

* Aeration imperfect † Doubtful

Table V

PUSH-PULL ENDURANCE TESTS IN AERATED SEA WATER (2300 CYCLES/MIN.)
Test-pieces: Scale-covered steel

Test	Stress, tons/sq. in.	Mean Temperature during Test, °F.	Endurance, cycles × 10^6			Remarks
			Actual	Corrected for 75° F.	Average for 75° F.	
OC_2	0±12·0	84	1·050	1·36	1·36	A
OC_7		80	0·485	0·57	0·62	B
OC_8		72	0·737	0·67		B
OC_{17}	0±11·3	68	1·248	0·01	1·01	B
OC_1	0±8·0	80	5·419	6·33	6·33	A
OC_{12}		70	1·572	1·35	1·94	B
OC_{16}		68	2·703	2·20		B
OC_9		75	2·266	2·27		B
OC_4	4·0±8·0	87	2·186	3·06	3·02	A
OC_5		86	2·702	3·69		A
OC_6		80	1·990	2·32		A
OC_{15}		75	1·931	1·93	2·02	B
OC_{16}		71	2·487	2·20		B
OC_{20}		76·5	1·830	1·92		B
OC_3	0±6·0	88	11·242	16·10	16·10	A
OC_{10}		78	3·859	4·24	4·60	B
OC_{11}		69·5	5·034	4·24		B
OC_{19}		72·5	5·774	5·35		B
OC_{13}	6±6·0	74	4·054	3·92	3·74	B
OC_{14}		70	4·870	4·18		B
OC_{21}		70	3·640	3·12		B

A: Scale unbroken when experiment was begun
B: Scale partially or wholly absent (cracked away) when experiment was begun

subjected to fatigue stressing. Different results were obtained by Gough and Sopwith,[5] who used a salt spray.

(*b*) For the stresses and the conditions of the surface of the specimens considered, the endurance was much the same when the mean stress was tensile as when it was zero. This may not be true of higher values of the mean stress, and it is quite possible that a corrosion-fatigue Gerber parabola[3] (*loc. cit.*, p. 69) may better express the results in a general manner. To explore the whole situation would demand a lengthy research covering high tensile stresses and small reversed stresses; the individual endurances in this case would be very large, and the total time involved correspondingly prolonged.

(*c*) With the testing system employed, failure always occurred at or near to the smallest cross-section of a test-piece, provided that the sea water was kept well aerated. With unaerated sea water it was found, in some preliminary experiments, that fracture occurred about 0·25 to 0·3 in. below the solution–air interface. This was not the position of highest stress, since the cross-section was about twice the minimal cross-section.

(*d*) Results for specimens covered with oxide are shown in Fig. 4. There are two curves:

(*i*) That for certain specimens on each of which the oxide scale (really two outer skins) was unbroken, when the experiment was begun.

(*ii*) That for the majority of the specimens, on each of which the oxide scale was partially absent before the experiment was begun; in some cases it cracked off completely when the experiment started. Below the scale was the third, innermost oxide skin.[6] This was of the same colour, grey-black, as the oxide scale, but could not be cracked away from the underlying metal. It will be observed that those specimens with broken oxide scale had much shorter endurance lives than polished specimens at the same stress values, and that specimens with unbroken scale had intermediate values.

The fatigue cracking invariably started at an imperfection in the scale, or, if the scale was partially absent, at the margin of some small adherent portion of the scale.

(*e*) For oxidized specimens which had been pickled so as to expose the bright underlying metal, with no adherent oxide whatever, the results are shown in Fig. 4. They indicate that pickled surfaces are no more prone to corrosion-fatigue than surfaces carrying scale. It would seem that pickling is not accompanied by an inherent weakening of the corrosion-fatigue properties, arising either from occluded hydrogen as such, or from hair-line cracks propagated by occluded hydrogen before it had escaped from the metal. On the other hand, broken scale is more dangerous than unbroken scale, doubtless owing to the presence of stress raisers and anodic spots at the interruption. It should be noticed that the scale studied was not rolling-mill scale, although its mechanical effects would probably be similar to those so produced.

(*f*) The results for oxidized specimens where the scale was interrupted by a narrow longitudinal band of bare metal are shown in Fig. 4. On these particular specimens the scale was partially absent before the

abrasion was carried out, and the endurances measured were longer than those of similar specimens which had not been abraded to expose a band of bare metal. This was anticipated, since, although the oxide film was more noble than bare metal, the latter probably conferred protection by acting as an auxiliary anode. The bare band was intensely corroded, but being relatively smooth at the outset, did not rapidly give rise to corrosion-fatigue cracking.

Although polished specimens (also pickled specimens) invariably showed numerous cracks apart from the one which ultimately led to fracture, samples carrying oxide never showed more than two auxiliary cracks. This suggested one reason for the short life of oxidized specimens. The scale-covered area constituted a large and very efficient cathode, and since the anodic points developed at weak places were few and small, the intensity of attack was great.

(*g*) A few specimens in the polished condition were re-abraded with very coarse emery cloth, to investigate whether such action would increase or decrease the corrosion-fatigue strength. Figure 3 shows the behaviour obtained. In three cases, the effect was that of improving the corrosion-fatigue endurance quite considerably, but in two others the value obtained was low. It would seem that a sharp, deep abrasion, cut by an exceptionally sharp piece of emery, might constitute a stress raiser, but, in general, that smooth scores cut by the ordinary rounded grains present on abrasive paper produce the effect of a peened surface, and by imposing residual-surface compressions improve resistance to corrosion-fatigue attack. This accords with the results of a recent research carried out on the effect of peening on corrosion-fatigue.[7]

CONCLUSIONS

It would seem that corrosion-fatigue is less dangerous for ships' hulls than McAdam's numbers would suggest, probably because he used a rotating machine. Pickling does not introduce serious sensitivity towards alternating stress, although pickled plates have a shorter endurance than polished steel. Broken particles of oxide scale produced by direct heating have a weakening effect, and broken mill scale would probably behave in the same way. The indentations and scores left by abrasive treatment, and the local removal of oxide scale by abrasion do not, however, constitute serious dangers. Most important of all, the superimposition of a tensile stress upon reversed stress, within the range studied, causes no serious deterioration of behaviour.

Future Work

Although the author will be unable to extend the experiments further, he would venture to make the following suggestions for future work:

Further information is desirable in regard to superimposing higher mean stresses. Mean stresses up to 20 tons/sq.in. should be examined, although, with the existing apparatus, this would necessitate the use of test-pieces with a much smaller diameter.

The testing of actual welded samples would provide valuable information. The welded test-pieces should be in a number of conditions for comparison, so that any undesirable qualities would be exposed, and measures could be taken to improve performance. Such conditions should include:

(*a*) Test-pieces " as welded "
(*b*) Test-pieces welded, and afterwards machined and polished so as to exhibit a good finish
(*c*) As (*a*), but strain-relieved at a suitable temperature below the lowest transformation point
(*d*) As (*b*), but strain-relieved at a suitable temperature below the lowest transformation point
(*e*) As (*a*) and shot-peened
(*f*) As (*b*) and shot-peened.

Table VI

PUSH-PULL ENDURANCE TESTS IN AERATED SEA WATER (2300 CYCLES/MIN.)

Test-pieces: Scale-covered steel, afterwards pickled to remove scale completely and expose bright metal

Test	Stress, tons/sq. in.	Mean Temperature, during Test, °F.	Endurance, cycles × 10^6		
			Actual	Corrected for 75° F.	Average for 75° F.
OPC_1	0±12·0	80	0·582	0·68	
OPC_2	0±8·0	76	2·815	2·90	2·83
OPC_4		71	3·127	2·76	
OPC_5		68*	1·176	0·95	
	4·0±8·0				
OPC_3	0±6·0	80	7·595	8·85	10·03
OPC_6		71	12·655	11·20	
OPC_7	6·0±6·0	80	7·464	8·68	8·38
OPC_8		75	7·618	7·62	
OPC_9		74	9·112	8·83	

* This specimen became deeply trenched in places where the pickling solution had attacked the metal adjacent to cracks in the mill scale, before the latter had been undercut

Table VII

PUSH-PULL ENDURANCE TESTS IN AERATED SEA WATER (2300 CYCLES/MIN.)

Test-pieces: Scale-covered steel, afterwards abraded to interrupt the scale by a narrow longitudinal line of bare metal

Test	Stress, tons/sq. in.	Mean Temperature during Test, °F.	Endurance, cycles × 10^6		
			Actual	Corrected for 75° F.	Average for 75° F.
BOC_1	0±12·7	69	0·595	0·50	0·50
BOC_2	0±8·0	72	4·168	3·80	3·80
BOC_3	0±6·0	71	9·083	8·03	8·03

Table VIII

PUSH-PULL ENDURANCE TESTS IN AERATED SEA WATER (2300 CYCLES/MIN.)

Test-pieces: Polished steel, afterwards re-abraded with very coarse emery paper (Durex No. 332–60)

Test	Stress, tons/sq. in.	Mean Temperature during Test, °F.	Endurance, cycles × 10^6		
			Actual	Corrected for 75° F.	Average for 75° F.
CC_2	0±12·0	81	4·834	5·80	4·00
CC_5		78	2·007	2·21	
CC_1	0±8·0	85	19·174	25·50	17·04
CC_3		81	7·535	9·02	
CC_4		77	15·570	16·60	

Acknowledgments

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Historical Note No. 9

Early Ironworking near Ticehurst, in Sussex

By Dr. H. R. Schubert

The "Dunn Collection," deposited at the Public Library of Hove, contains twenty-one records regarding ironworking in the south-eastern part of Sussex from 1433 to 1715. These records represent a valuable supplement to Straker's "Wealden Iron,"[1] which was published in 1931, that is, before the Dunn Collection was deposited at Hove.

The earliest of these records is a grant dated 12th July, 1433, by which one Richard Burdon, of Hadlow, near Tonbridge (Kent), was allowed to pay by seven yearly instalments of 13*s.* 4*d.* for the acquisition of land in the parish of Ticehurst called "Croucheland," together with a pond and a piece of land on which there was a forge ("*cum stagno et loco pro fabrica existente*"), which property formerly belonged to one Simon Payn.[2] Evidence of a Simon Payn living in the district is supplied by a document of 1382 by which he was granted pardon for not paying his ransom for a trespass committed against Robert, Vicar of Ticehurst.[3] From these two documents it may be inferred that there was a forge in the parish of Ticehurst working from 1382 to at least 1433.

Straker refers to four different sites of ancient ironworks in the parish, namely, Bardown, East Lymden, Hammerden (near Ticehurst Road station), and Shoyswell, the only evidence being supplied by cinder heaps still existing, and in the case of East Lymden by field-names such as "Furnace field," and "Furnace Shawfield."[4] The question is whether the site of the ironworks mentioned in the document of 1433 was near any of the four ancient ironworks referred to by Straker. In 1567, according to a survey of the Manor of Robertsbridge (Sussex), one Anthony Graylinge was copyholder of five parcels of land containing some 18 acres "lying together at Bardowne."[5] This land was situated between the highway leading from Wadhurst to Burwash on the west, the highway from Ticehurst to Stonegate on the east, and the highway from Bardown to Ticehurst on the north, that is, in the triangle at present formed by the roads from Bardown to Stonegate and from Stonegate to Lymden, and by the little river Lymden in the north. Two of these five parcels were called "the Uppermedes," *i.e.*, meadows probably near the river. One parcel was named "Orpitts," indicating a place where ore was formerly mined, and another was named "Croochefeld," which appears to be synonymous with the field-name "Croucheland" in the document of 1433. From this evidence it may be suggested that the ironworks of 1433 was somewhat east of Bardown, the river Lymden supplying the pond with water. This is quite near a site where vestiges of Roman ironworking of the second half of the first century A.D. were discovered in 1909.[6]

Just outside the parish of Ticehurst was another ironworks, new evidence of which is supplied by a record of 1568, also preserved in the Dunn Collection. This is the furnace of Darfold, in connection with which the only evidence available to Straker related to 1574 and 1588.[7] On 1st February, 1568, Sir Robert Tyrwitt, of Lincolnshire, granted to Thomas Gleyd (*i.e.*, Glide) of Burwash, yeoman, a lease of Etchingham Park, "Darvol furnace," and the forge at Etchingham, with "all their woods and underwoods to make coal, as shall be necessary to make iron," for ten years. The rent was five-twelfths of the iron produced, "that is one cwt. and a quarter of it in every three cwt. of the iron made at the forge," to be paid weekly.[8] The restrictions imposed for the preservation of timber are of interest, it being demanded that the tenant should not fell any wood or underwood branching on the stubs of trees, "nor any streight young okes," that is, young oak trees as long as they are growing straight.

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[1] E. Straker, "Wealden Iron." London, 1931 : G. Bell and Sons, Ltd.
[2] Public Library at Hove, Dunn Collection, Box *J*, 9.
[3] L. J. Hodson and J. A. Odell, "Ticehurst," p. 76. Tunbridge Wells, 1925.
[4] "Wealden Iron," pp. 296–297.
[5] Sussex Record Society, vol. 47, p. 89. Lewes, 1944.
[6] F. Haverfield, "Roman Remains from Ticehurst," Sussex Archaeological Collections, vol. 58, p. 195. Lewes, 1916. *See also* Victoria County History of Sussex, vol. 3, p. 31. London, 1935.
[7] "Wealden Iron," p. 297.
[8] Public Library at Hove, Dunn Collection, Box *L*, 712.

DISCUSSION ON PAPERS

DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Symposium on the Peeling of Whiteheart Malleable Cast Iron

A meeting to discuss the peeling of whiteheart malleable cast iron and the penetration of sulphide in the carburization of steel was held at the Offices of The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, on Thursday, 8th April, 1948, at 2.0 P.M. Members of the Institute of British Foundrymen and of the staffs of member-firms of the British Cast Iron Research Association had been invited to attend, and the Chair was taken by Mr. J. G. PEARCE, Director of the British Cast Iron Research Association. The meeting was preceded by a buffet luncheon at the Offices of the Institute.

The papers discussed were: "Symposium on the Peeling of Whiteheart Malleable Cast Iron," with an introduction by J. C. W. Humfrey, O.B.E., and papers by J. Bernstein, J. S. Bowden, K. J. Irvine, A. Preece, A. E. Probst, and G. R. Webster (*Journal of The Iron and Steel Institute*, 1948, vol. 158, Jan., pp. 1–36), presented by Mr. J. C. W. Humfrey, and "Sulphide Penetration in the Carburization of Steel," by A. Preece and K. J. Irvine (*Journal of The Iron and Steel Institute*, 1947, vol. 157, Nov., pp. 336–343), presented by Mr. A. Preece.

The **Chairman** (Mr. J. G. Pearce), in opening the meeting, said: I am quite certain that we are all very grateful to The Iron and Steel Institute for arranging this Symposium and for giving us the opportunity of meeting and exchanging views and ideas with respect to the peeling of whiteheart malleable. There is a very large measure of agreement on the causes of peeling in whiteheart malleable, and possibly the discussion will emphasize that point. We are also conscious, however, that the individual authors differ in their views in certain respects. It would be an excellent result if this discussion enabled any conflicts of view to be reconciled and general agreement to be reached.

Mr. **J. C. W. Humfrey** (Messrs. Riley, Harbord and Law), in introducing the papers in the Symposium, said: All the papers agree on one point, namely, that the sulphur in the peeled layer is introduced into the castings from the ore or furnace gases, and the failures only became serious when, owing to war conditions, Riff ore containing anything up to 0·2% of sulphur was used in the annealing pots as a substitute for Cumberland ore. The papers also agree with previous work on the microstructure of the peeled layer.

After a brief reference to the main significance of Preece and Irvine's paper he gave a short account of the work of the authors of the other papers, and of the conclusions at which they arrived.

Mr. Humfrey concluded by suggesting that a point which might usefully be dealt with in the discussion was the precise influence of silicon on peel formation. Preece and Irvine produced typical peel in white iron and silico-manganese spring steel, but did not show any similar effect on a low-silicon straight carbon steel. While sulphur penetration was obtained on a 0·73% carbon steel, the sample had not been given a surface decarburization, and no concentrated layer of sulphide was formed. It would be of interest, in view of Mr. Bowden's equations, to carry out further experiments on a surface-decarburized sample or samples and to see whether the peel effect was produced with the same facility as with a high silicon content.

Mr. **A. E. Peace** (Ley's Malleable Castings Co., Ltd., Derby), in opening the discussion, said: This Symposium presents to us a happy combination of papers. We have the academic approach of Preece and Irvine, with but little attempt to simulate works conditions. We have an academic approach by Bernstein, with a considerable effort to simulate works conditions, and then we have the practical experimentation of Webster and Probst, and of Bowden. The great variety of approach to the problem adds weight to the conclusions on which the various investigators agree, and I think that it does offer possibilities of explanation where they do not agree. Preece and Irvine raise the important point that before

the investigation there was agreement on the fact that sulphur in the annealing ore was a necessary factor, but there was disagreement regarding the essentially oxidizing nature or otherwise of the atmosphere. That, I think, raises what still remains the outstanding feature of these papers.

The rôle of the metal composition appears to be free from any major dispute, though I think that there are certain features which leave us a field for interesting discussion. I propose to dwell, however, rather more upon what I regard as the major aspect of this work.

Apart from the work of Webster and Probst, little attention was given to the state of the sulphur in the annealing ore. Webster and Probst give some details of total volatile sulphur and fixed sulphur. I wonder whether, when speaking of volatile sulphur, they refer to sulphur which is evolved by acid solution. In my own laboratory it was customary to determine the total sulphur in the ores and also the sulphur evolved in hydrochloric acid solution. An interesting feature of all our results was that the fixed sulphur remained approximately constant in all spent ores for a specific new ore in use, and there was a direct relation between this fixed sulphur and the sulphur content of the new ore. For example, Thabazimbi spent ores, although the total sulphur content of the ore may have been 0·3 or 0·4%, had no more than about 0·06% of fixed sulphur, the remainder being capable of evolution by hydrochloric acid. With Riff ores the fixed sulphur in the spent ores was always around 0·15%.

That raises an interesting point as to the reactions of the pyrites. I think we may take it that in the Riff ore, which was the major cause of the peeling experienced during war-time, the sulphur was essentially in the form of pyrites, and there does appear to be some reversible reaction of the sulphur to and from the pyrites.

Some years ago Nicol-Smith suggested, in a report presented to Dr. Brynmor Jones,* a theory of sulphide penetration depending on oxidation of ferrous sulphide to pyrites, and reduction of pyrites to sulphide, the sulphide dissolving iron at its inner surface and depositing iron or iron oxide at its outer surface.

Bowden's ingenious theory of the carbonyl sulphide reaction provides in one grand sequence the sulphide, the oxide, and the carbide phases which are significant in peeling. This seems too good to be true and hardly leaves room for the action of the various eutectics to which Bowden himself later refers, and upon which so much emphasis is placed both by Bernstein and by Preece and Irvine.

Preece and Irvine do not put forward a theory regarding the sulphide penetration in whiteheart malleable, but they advance much evidence relative to the possibility of a liquid eutectic of the oxide and sulphide being the penetrating medium. Bernstein emphasizes the iron/iron-sulphide eutectic and, if I read him aright, rejects the oxide eutectic. I am open to correction there. Timmins† put forward the theory of an additive compound of carbon monoxide and sulphur dioxide, suggesting that it was stable only in weak oxidizing conditions, and that it reacted with iron to form iron sulphide. Nicol-Smith suggested the theory mentioned above, and Brynmor Jones* suggested a very complex series of reactions involving liquid eutectics of sulphide with iron, iron oxide, and iron silicate. There is much evidence to substantiate the possibility of each of those, both by temperature and by the fact that these eutectics melt at from 940° to 990° C, and we are all fully aware of the evidence of oxides and silicates in the peel.

I previously held a gaseous theory, involving sulphur dioxide penetrating by the intergranular oxide, as suggested by Webster and Probst. But I believe now that the weight of evidence is very heavy on the side of the liquid eutectics reaction and I am in favour of that theory, although I believe that the same reaction may not take place in every case of peel.

I should like now to refer to what I think is a very important matter, the question of the oxidizing nature or otherwise of the atmosphere. Bernstein states that a high new-ore/used-ore ratio will encourage peel, while Preece and Irvine say that prevention is to be found in the use of ore mixtures containing adequate proportions of ferric oxide. Bernstein's remarks may be contrasted with Bowden's experiment with the graphite rod. Again, Bowden shows in Table II the regenerative effect of an oxidizing oven atmosphere upon the spent ore, and conversely of the reducing action of the bad atmosphere in oven *A*, in which case, incidentally, it is obvious that the gases were highly sulphurous.

The practical demonstration of removing peeling troubles by increased ore strength and oxidizing oven atmosphere, as given in Bowden's paper, page 13, ought to be convincing, but I must confess that I am not convinced, by reason of other experiences. For example, in a statistical investigation it was found that peel was more prevalent in bottom pots than in top pots, although the temperatures at the bottom of the oven were appreciably lower than those at the top. This is ascribed not to temperature effect but to the action of the oven gases, which are preferentially drawn in at the bottom, owing to the use of an on-and-off heating cycle and the upward temperature gradient which is obtained within the pots. In this investigation, a 5/1 Riff ore mixture produced much greater peel than an 8/1 mixture of the same ore, although the sulphur contents of both mixtures were almost identical.

Bowden's conclusions (page 14) agree generally with those of Preece and Irvine and of Bernstein, but the maximum emphasis is placed on the effect of a rich carbon monoxide atmosphere, which is contrary to Bernstein's findings.

Webster and Probst find that oxidizing conditions are favourable to peel. This is also supported by Neath and Longden,* and by my own experience. I believe that it is possible for us to reconcile these divergences of experience, and I feel that the gaseous-decarburization work of Preece and Irvine and of Bernstein is going to point the way.

The primary process in whiteheart annealing is decarburization. We do not know enough about the various stages involved and the differential rates of the reactions. We must have a rate of carbide dissociation, of solution in austenite, of diffusion through austenite, of oxidation of carbon, of nucleation of graphite, and of crystallization of graphite. It is probable that at different stages of the process some of these reactions take charge and govern the rate, while at other stages some other reaction may be governing the speed of the process.

There is quite a body of opinion which holds that a necessary part of peel formation is a decarburizing rate which is out of balance with the diffusion rate, and consequently gives freedom for oxidation of the metal, which I think throughout all the papers has been shown to be an essential requirement in the formation of peel.

Mr. **Ivor Jenkins** (General Electric Co., Ltd.) : Dealing first with the paper by Preece and Irvine, on sulphide penetration in the carburization of steel, the theory

* Brynmor Jones, " Problems Related to the Whiteheart Malleable Cast-Iron Process." Extra-Mural Research Report No. 22. D.S.I.R., February 1944.

† A. A. Timmins, " Formation and Prevention of Peeling in Whiteheart Malleable Cast Iron." Iron and Steel Control, Mar. 20, 1944.

presented by them to explain the mechanism of diffusion of the sulphide band into the steel appears to be indisputable, but there are one or two points of detail which I should like to raise. For example, the carbon content of the Armco iron is not quoted, but I presume that it was not zero. If so, was there a build-up of carbon in front of the advancing sulphide band as carburization proceeded? If this did occur, presumably conditions would be reached, eventually, comparable to the early stages of penetration of sulphide into a low- or medium-carbon steel, and the sulphide band would disperse.

The constant depth of penetration in a given time of the sulphide within the temperature range of 1000–1200° C is, at first view, surprising, and I find it difficult to accept the authors' explanation for this, which calls for a somewhat fortuitous balancing of the increased rates of diffusion of iron through the sulphide band and of carbon into the carburized layer with the decreasing rate of absorption of carbon at the surface. The rate of penetration of the sulphide is determined by the difference in carbon potential on either side of it. The carbon potential at the interface of the sulphide will remain constant for a given penetration, irrespective of temperature, and in view of the fact that the change in carbon content in the carburized zone within the temperature range 1000–1200° C is not likely to be very great, I suggest that the controlling factor, with regard to the depth of penetration, is the carbon potential on the inner face of the sulphide. This would explain the fact that an increase in temperature has no effect on the depth of penetration. Have the authors experimented with carburizing mixtures containing hydrocarbon gases, which would eliminate the complications due to the increasing stability of carbon monoxide with rising temperature?

The Armco iron shown in Fig. 6, carburized for 20 hr in carbon monoxide at 1000° C, shows, if my calculations are correct, a case depth of about 0·8 mm, which does not agree with the data given in Fig. 3. Also, the statement (page 341) regarding the solidification of isolated sulphide particles could be readily misinterpreted. The authors should state definitely that the mechanism involves the absorption, by the austenite, of iron from the molten sulphide and not of iron by the sulphide from the austenite, which, if interpreted that way, would be quite contrary to the theory of sulphide penetration so ably developed by the authors.

In their paper on the peeling of whiteheart malleable, the same authors have demonstrated very clearly a mechanism whereby the characteristics of peel can be produced. In arriving at this, however, I feel that they have made certain assumptions, and omitted certain experimental observations, which might be queried. In the first instance, they state (page 3, and again on page 6) that in the malleablizing process there is a continual change in composition of the gases in the annealing box, tending toward a higher carbon monoxide concentration. Is this hypothetical, or is the statement backed by experimental evidence?

Reporting on the depth of intergranular oxidation in sulphur-free $CO + CO_2$ mixtures (page 5), it is stated that this is of the same order for all three irons used in the experiments. Is not this rather surprising, in view of the fact that one of the irons had already been annealed, so that the rate of arrival of carbon atoms at the surface would be much less than for the as-cast materials, and hence the penetration of oxygen would be more readily effected? Or would the authors consider that the lower silicon content of the malleablized iron might have countered this anticipated effect?

In mixtures of carbon monoxide and carbon dioxide containing 0·3% of sulphur dioxide, increasing the carbon dioxide up to 10% gave appreciable sulphide penetration, but beyond 15% of carbon dioxide there was little or no sulphide formed. This suggests that within this range of composition a state of chemical equilibrium is set up between the three components of the furnace atmosphere and the solid phase. If there is a concentration of sulphur dioxide over the iron comparable with that added to the atmosphere, then:

$$FeS + 2CO_2 \rightleftharpoons Fe + SO_2 + 2CO$$

This is a reversible reaction for which the equilibrium constant at any fixed temperature is given by the following equation:

$$K_T = \frac{P_{SO_2} \cdot P^2_{CO}}{P_S \cdot P^2_{CO_2}}$$

The factor P_S represents the partial pressure of the sulphur in solid solution in the iron, and is therefore dependent upon the concentration of sulphur in solution. Desulphurization is promoted by high carbon dioxide values and low concentrations of sulphur dioxide and carbon monoxide; sulphurization is promoted by the reverse. Results reported by Bernstein, and by Preece and Irvine, are in accordance with the reaction to which I have referred.

In the experiments detailed on page 6 by Preece and Irvine, the atmospheres used in the later stages of the treatment, involving mixtures of increasing carbon monoxide content, theoretically at least, become carburizing to the iron. Neglecting the effect of 0·1% of sulphur dioxide, which should be negligible in this connection, the theoretical equilibrium surface carbon contents for the various stages of the treatment are as follows:

CO_2, %	Carbon, %
15	0·07
10	0·10
5	0·25
2½	0·40

The authors have not reported on any observed recarburization. Was this obtained? If so, what relationship do they consider that this treatment bears to peeling in practice where, from the evidence of photomicrographs of etched specimens elsewhere in the Symposium, there is no apparent carburization at the surface of the iron? Again, peel formation, in this experiment, was markedly developed after treatment in the atmosphere containing 2·5% of carbon dioxide, which should be carburizing. Coincidental with this, from Figs. 12 and 13, there appears to be a marked change in the character of the intergranular oxidation which is now more highly dispersed and takes on the appearance of a grain-boundary network. Would the authors care to comment on this, and has it any significance in relation to the consolidation of the sulphide band?

On page 7 it is stated that a scale is produced on iron treated in 80% CO/20% CO_2/0·3% SO_2, the scale containing FeS and FeO. This is surprising, in view of the fact that the ratio CO/CO_2 is still well on the reducing side with respect to iron oxide. I should like to ask the authors what method of identification was used for the oxide constituent of the scale? If it was solely metallographic, would they consider it possible that the oxide component might have been a silicate? This is most important in arriving at a satisfactory explanation of peeling.

The authors state that the presence of an intercrystalline network of silicate is not essential to the accompaniment of sulphide penetration, and, in support, refer to their experiments on plain carbon steel. When giving details of these experiments (page 7) they describe how

the sulphide dissolves and carries away with it particles of manganese sulphide and "other impurities." What are these other impurities? Could they have been silicates?

Bowden submits fairly conclusive evidence that peeling is promoted by lean ores and smoky combustion conditions, which tends to confirm the findings of Preece and Irvine. Whilst data are quoted of the gas composition in the annealing can in normal practice, it is very surprising that there is no evidence of any attempt having been made here, or elsewhere during this work, to analyse the gases obtaining under conditions which promote peeling, and which could be readily simulated in the light of the experimental work.

Bowden associates the silicate network with the formation of peel, but his suggested chemical reactions and mechanism would seem, perhaps, unnecessarily complex. By what mechanism does he conceive of complex molecules diffusing into the iron and reacting in the manner described? Could he not have arrived at the same end-products of his reactions by assuming the diffusion of the individual reacting elements, namely, carbon, sulphur, and oxygen, which would seem to me more in accord with the basic principles of diffusion in the solid state?

Again, the suggested mechanism of the coalescence of silicate or eutectic particles is rather difficult to accept. Is it possible to conceive that the migration of molten particles is actuated by atomic ordering or disordering at grain boundaries, which is what grain growth really involves? Is it not more probable that such coalescence is associated with growth of the particles by diffusion of oxygen and silicon to them, or alternatively by re-solution of smaller particles having a high solution rate, diffusion, and re-precipitation on the larger particles?

The work of Webster and Probst demonstrates fairly conclusively that a high-sulphur-bearing ore can be a contributory factor to peeling. I would question, however, their statement (page 19) that sulphur dioxide is a reducing agent, and that it is not expected to attack the metal during malleablizing.

Bernstein concludes that in sulphur-rich ores variation in ore strength is of little consequence. Presumably ore mixtures richer than a ratio of 3/1 of used-ore/new-ore in his experiments reduce the amount of peeling because of the countering effect of a higher carbon dioxide content in the can on the sulphur dioxide in the atmosphere, in accordance with the equation which I have already given:

$$FeS + 2CO_2 \rightleftharpoons Fe + SO_2 + 2CO$$

Ore mixtures leaner than 6/1, on the other hand, would promote a higher carbon monoxide content in the can, reducing the rate of decarburization and thus the rate of peel formation, again in accordance with that equation. In the light of this, variation in ore strength could be most important.

The curves of carbon and sulphur distribution in castings annealed in ore for varying times are particularly interesting. I am surprised that the author has not drawn attention to the fact that in Figs. 21 to 25, which indicate these distributions, the maxima in the sulphur-distribution curves correspond to approximately the same carbon content—about 0·5–0·6%. This itself is evidence of the extent to which the penetration of the sulphide band is controlled by the degree of decarburization, and is very significant.

I cannot see that there are any grounds for the assumption that the maximum in the sulphur-distribution curve, falling off to a lower sulphur content at the surface, is associated with desulphurization of the casting during the later stages of malleablizing. I would suggest that an alternative explanation is that the build-up of sulphur inside the casting is associated with migration from the surface and subsequent internal zones towards the core of the casting. Such migration is promoted by maintaining around the outside of the casting an atmosphere sufficiently rich in sulphur to prevent desulphurization, in accordance with the equation to which I have referred. That is confirmed by the fact that according to Bernstein's curves the overall pick-up of sulphur by the castings has not been very great, even after treatment for 150 hr. Where the sulphur content of the ore is low, this migration and build-up of the sulphur does not occur, because of the natural concentration gradient set up owing to desulphurization at the surface. The different character of the sulphur-distribution curve in Fig. 29, obtained in Bernstein's experiments in gaseous malleablizing, is due simply to the stronger sulphurizing power of the atmosphere used, containing 1% of SO_2, which is likely to be much greater than that generated from ores containing 1% of sulphur.

I would further suggest, as Bowden has already indicated, that the formation of a sub-scale of oxide or silicate is a necessary preliminary to the development of the type of peel with which this Symposium is primarily associated. The formation and penetration of such a sub-scale will be promoted more readily the more the iron is decarburized, when the rate of arrival of carbon atoms at the surface has decreased sufficiently to permit of the diffusion into the iron of oxygen atoms adsorbed on the surface. The oxygen in solution then oxidizes, preferentially, the silicon, and the silicates so formed provide the nuclei for the formation of complex eutectics of sulphide and silicates, the sulphur in solution in the iron diffusing to them to form eventually particles which are molten at the malleablizing temperature. Subsequent diffusion of the molten complexes away from the surface cleans up the iron, at the surface, of sulphur, and to a certain extent of silicon—and I would mention here that a silicon-distribution curve would be very useful in that respect—and results in the form of sulphur distribution indicated in Bernstein's paper.

Such a mechanism would account for many of the observed facts. A higher silicon content will promote peeling because of the greater number of nuclei of silicates available when intergranular oxidation proceeds; a high manganese/sulphur ratio reduces peeling because of the lower concentration of sulphur in solid solution available for the formation of molten complexes; decarburization in atmospheres rich in carbon dioxide reduces peeling, since desulphurization of the iron is also effected; and decarburization is a necessary preliminary to the formation of peel, since it determines the extent of the initial oxide penetration.

If such a mechanism is correct, an explanation is still required for the means whereby the sulphide band migrates inwards into the iron. It is necessary to assume that the sulphide band would permit of the diffusion through it of carbon as well as of iron, otherwise diffusion of the band would cease owing to the build-up of carbon in front of it. As the band is not pure iron sulphide or an iron/iron-sulphide complex, this assumption may not be unreasonable. Again, Bernstein says that the formation of the divorced pearlite band is probably associated with segregation during cooling. Perhaps he would agree, however, that the evidence so far submitted is not conclusive, and that this aspect of the problem could with advantage be more thoroughly investigated, especially with regard to the effect of local concentrations of non-metallics, such as oxygen and sulphur, upon the solubility and segregation of carbon.

Mr. **P. F. Hancock** (Birlec, Ltd.): The evidence presented in these papers seems largely to agree in

suggesting that the main agent in peel formation is inward penetration of sulphur into the iron from an external source, which may be the ore or other decarburizing medium, or the furnace atmosphere. Other characteristics of peel, such as the formation of oxide silicate complexes in the peeled layer, and the segregation of carbon at the peel–metal interface, are shown to be secondary effects, consequent on the sulphur penetration.

Bowden, however, advances the theory that carbon monoxide is the primary agent, causing preferential oxidation of silicon, simultaneous sulphiding being due to carbonyl sulphide. This theory is discounted by practical experience in the gaseous annealing process, where atmospheres of high carbon monoxide contents, accompanied by significant amounts of COS (up to 0·03% by volume), derived from reaction of the atmosphere with the sulphur content of the castings, are present throughout the anneal, yet no peeling has ever been experienced.

While, then, it may be taken as established that sulphur from an external source is the cause of peel, there seems to be some divergence of view as to the precise conditions under which massive penetration, with formation of a continuous band of sulphide, occurs. Preece and Irvine in their former paper indicate that this takes place only in the presence of gas mixtures high in carbon monoxide, the mechanism presumably being similar to that described in their second paper. Mixtures of carbon monoxide and carbon dioxide with more than 95% of carbon monoxide are appreciably carburizing at 1000° C, and some recarburization of the previously decarburized iron would be expected under these conditions. It would be interesting to know if this did in fact occur. If so, the conditions of their experiments would not seem to be quite parallel to those under which peel arises in industrial ore-annealing, since marked recarburization of the surface layers is not normally an accompaniment of peel formation, and indeed it is difficult to see how gas mixtures high enough in CO to cause active carburization could arise as long as the ore retained an appreciable content of oxygen.

Bernstein's experiments with gaseous atmospheres, on the other hand, showed that peel could arise in sulphur-containing CO/CO_2 mixtures, with CO_2 contents up to 20%, the depth of peel increasing with the degree of decarburization, but being otherwise not closely related to the CO and CO_2 contents of the mixtures. Moreover, some of his results in which the specimens were air-cooled from the top temperature, *e.g.*, that illustrated in his Fig. 20, indicate clearly that sulphide penetration and formation of a sulphide band are not accompanied by any abnormality in carbon distribution at the annealing temperature. The peculiar distribution of carbon in the neighbourhood of the sulphide concentration, normally seen in commercial peeled samples, evidently arises only during slow cooling.

Again, Preece and Irvine, in an experiment described in their first paper and illustrated in Fig. 14, in which a high-carbon steel coated with sulphide was treated in CO, showed that penetration of sulphide could occur without any appreciable change in carbon distribution.

Thus apparently it is possible for sulphide penetration to take place either in the same direction as carbon diffusion, or in the opposite direction, or unaccompanied by any movement of carbon. At first sight this suggests that sulphide penetration is not directly related to carbon distribution; yet on the other hand there is abundant other evidence to show that it is; for example, the well-established fact that peeling occurs only after a certain amount of decarburization has been effected. Possibly, the sulphide penetration is related not directly to carbon diffusion but to other changes which accompany it; for example, changes in oxygen content.

Certainly, the mechanism of peeling is as yet by no means clear, and further experimental work would be needed to elucidate it. In view of the complexity of the phenomenon, it is suggested that in any further experimental work the maximum elimination of variables should be attempted, in order to simplify the interpretation of results.

In this connection some minor criticisms may be made of the experimental methods employed in these present investigations.

Firstly, one would have suggested some experiments with iron–carbon alloys substantially free from silicon and manganese. This would have eliminated the confusing effects of preferential oxidation of these constituents in the surface layers, which inevitably accompanies decarburization of commercial irons in CO/CO_2 mixtures, even when peeling is absent. It may be noted that Preece and Irvine employed Armco iron for some of the experiments described in their second paper, presumably for this reason.

Secondly, with regard to the addition of sulphur to the CO/CO_2 or other gaseous mixtures used, both Bernstein, and Preece and Irvine employed sulphur dioxide. Surely this was illogical, since SO_2 is oxidizing to iron, and is not stable in the presence of appreciable percentages of CO or hydrogen, being largely converted to COS and H_2S. Thus the confusing factor of surface oxidation of the iron was introduced; this would have been avoided if H_2S had been substituted, or if the gas mixture containing SO_2 had been preheated to allow it to stabilize before coming in contact with the specimen.

A third criticism relates to the question of gas flows used in gaseous annealing experiments. Bernstein draws various conclusions as to the decarburizing effects of different mixtures, when clearly the limiting factor in the experiments described was the rate of flow, and not the composition of the mixture. Again, Preece and Irvine in their second paper describe experiments on sulphiding and carburization in carbon monoxide atmospheres, at different temperatures, from which the conclusion was drawn that the rate of penetration was unaffected by temperature. Here again, one wonders whether the flows employed were high enough to ensure the maximum rate of absorption of carbon; consideration of the equilibria involved shows that an approximately ten-fold increase in the minimum flow is needed over the range 1000–1100° C to ensure maximum absorption. If account were not taken of this factor, the rate of penetration would have been governed largely by the gas flow and not by any inherent characteristics of the penetration process.

One further point may be mentioned. Since marked changes in the distribution of carbon and possibly of other constituents in the peeled layer occur with slow cooling, as Bernstein's illustrations show, it might have been advantageous to quench at any rate some of the treated specimens from the top temperature in order to preserve as nearly as possible the structure existing at the annealing temperature.

It is very satisfactory to know that the occurrence of peeling is impossible with the gaseous process, in which the annealing atmosphere is derived from a sulphur-free medium such as air or steam. In view of the practical success of gaseous annealing, which is now firmly established on the industrial scale, no doubt the phenomenon of peeling would in any case automatically disappear as the older process is superseded by the gaseous method.

The **Chairman**: In thanking Mr. Hancock for his contribution, we ought to keep in mind that these

investigators were operating against time on an urgent practical problem, and that they were more concerned at that time with the way to prevent peeling than with the mechanism of its formation.

Mr. **H. Morrogh** (British Cast Iron Research Association) : I feel that we ought to emphasize once again that peeling is due to the external supply of sulphur to castings during annealing, and that if that external sulphur is not present, peeling will not occur. A recommendation should therefore be made to the malleable-iron industry that there is only one certain way to avoid peeling, and that is by avoiding the use of sulphur-containing ores or sulphur-containing atmospheres, and that we have not sufficient evidence to recommend a guaranteed procedure for the avoidance of peeling if the ore is sulphurous.

It is apparent that peeling is caused by the inward penetration of the sulphur and its concentration at a certain point from the edge of the casting. There is considerable disagreement as to the precise effect of oxidizing or highly decarburizing atmospheres. The point raised by Mr. Jenkins should be considered more thoroughly and I suggest that the particular maximum sulphide penetration reported by Preece and Irvine represents that obtainable at a specific sulphur content in the atmosphere, and that with different sulphur contents in the atmosphere the peak, if it occurs at all, will occur at a different point.

Preece and Irvine appear to believe that oxidation is a necessary preliminary to the development of peeling, but Bernstein assumes that sulphur penetration occurs first and that oxidation follows it. The establishment of the mechanism of peeling must resolve this point, and it seems that it would be resolved by the study of the decarburization of white iron and its sulphurization under conditions which are not oxidizing, for instance, in hydrogen/hydrogen-sulphide atmospheres. I can say that it is possible to produce peeling under those conditions when no oxide phases are present at all, and therefore I feel that we might at this stage conclude that prior oxidation is not necessary for peel formation.

We may easily be misled by studying the microstructures of slowly cooled peeled samples. Bernstein has shown that the structure of rapidly cooled metal containing the sulphur concentration differs considerably from that in slowly cooled samples, and has suggested that the concentration of carbon at the peel interface is due to a reaction occurring on slow cooling. I think that is correct. In this context, Mr. Jenkins raised the point of whether there is any evidence that carbon monoxide increases during the progress of an anneal in an ore annealing can. I have seen the results of several attempts to determine the gas content of annealing cans during annealing, and in every case they showed a substantial increase in carbon monoxide content and a decrease in carbon dioxide content during the anneal. He also raised the question of whether recarburization can occur. I can assure him that that is so, and that malleable-iron castings can be produced with a continuous film of cementite all round the periphery ; it has been possible to reproduce that condition in gaseous atmospheres by changing to a high carbon monoxide content on cooling, particularly below the critical point.

Preece and Irvine suggest that the banded structure in Fig. 5 of their paper on peeling is due to the removal of silicon. What proof have they of this ? The preferential oxidation of silicon has been referred to on a number of occasions, but no evidence is produced, I believe, in these papers to show that there is removal of silicon.

I have been in contact with some of this work while it was being carried out, and in connection with the effect of silicon and manganese one very striking fact emerges : even with high manganese contents, when the silicon content is high the production of peeling is manifest by the formation of iron sulphide and not manganese sulphide. One is tempted to inquire what has happened to the manganese, and why silicon apparently inhibits its action in combining with sulphur.

I find it difficult to picture how the reactions suggested by Bowden could move progressively inwards, and I should like to ask in what space he assumes that the carbon monoxide and carbonyl sulphide molecules could exist, and by what process the silica particles are swept forward. Referring to the X-ray examination of the sulphide, he comments that it has a super-lattice structure ; is this term used in the sense generally accepted by physicists, or does he merely mean an iron–sulphur complex containing more sulphur than one would expect from the formula FeS ?

Bowden also refers to growth in grey-iron castings, which he says increases with increasing silicon content and may be attributed to the preferential oxidation of silicon. It is a fairly well-known fact that the increased growth due to silicon in grey cast iron is due to its effect on the stability of the pearlite. Moreover, when the silicon content is raised above about 2·5% its effect on growth is progressively to reduce it.

Bowden's suggestion that the epidemic of peeling troubles, which was in certain quarters attributed to the use of Riff ores, was primarily due to the use of weak ore mixtures, rather implies that the high sulphur content of Riff ores was not the prime cause. I should therefore like to propose that some authoritative body should consider this work and make a recommendation to the industry and to the suppliers of annealing ore, giving a safe upper limit for the sulphur content of that ore. The industry may in the future be faced with a similar problem, and it is very difficult from this work as it exists at the moment to make a suitable practical recommendation upon that point.

The **Chairman** : I am going to ask Dr. Schulte to continue the discussion. He is peculiarly competent to do so, because he not only participated in the original work* by Baukloh, Friederichs, and himself, which was translated† by the Institute, but was also largely concerned both with the design and with the operation of the tunnel furnace at Remscheid, which was uncovered by Mr. Morrogh's B.I.O.S. team, and with the gaseous annealing of malleable carried out by the Bergische Stahl-Industrie.

Dr. **F. Schulte** (Birlec, Ltd.) : The oxidizing power of ore mixtures is of great significance and may affect the results of the annealing process in many different ways. It affects the speed of decarburization and the possibility of partial oxidation of metal and has quite a distinct influence on the question of sulphurization or desulphurization.

Normally the furnace atmosphere will be oxidizing to iron, even if combustion is carried out with a certain deficiency of air. I think that the conditions in Bowden's furnace *A* must be quite exceptional, because to make the combustion atmosphere so strongly reducing that some of the iron ore is actually reduced to metallic iron requires such a marked lack of combustion air as to result in a very low thermal efficiency. In the early

* *Archiv für das Eisenhüttenwesen*, 1943, vol. 16, Mar., pp. 341–354.

† *The Iron and Steel Institute*, 1943, *Translation No.* 158.

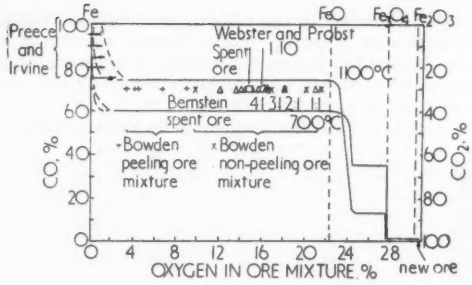


Fig. A—Reduction of iron oxides with CO–CO_2 mixtures (Schenck and co-workers)

stages of the annealing time the gaseous reaction products formed inside the can will prevent the entry of furnace gases.

Even if we assume that normally towards the end of the annealing time some of the combustion gases enter the annealing can, they should theoretically come into equilibrium with the iron-ore mixture and with the castings. I say "theoretically" because in practice things may be somewhat different. We can expect to get uniform gas composition inside the pot only if there is sufficient space between the particles of the ore mixture to allow of rapid diffusion.

The conditions which arise when iron oxides are reduced with mixtures of carbon monoxide and carbon dioxide have been investigated by Schenck and his co-workers, and Fig. A shows gas compositions for 1100° C and for 700° C plotted against the oxygen content in the ore mixtures. I plotted into this diagram the ore compositions as given in this Symposium, calculating the oxygen content as a percentage of the sum of iron and iron oxides. All the new ores mentioned consist mainly of Fe_2O_3, having about 30% of oxygen. The ore mixtures all lie between about 21½ and 3% of oxygen, and it will be seen from this illustration that theoretically they should all give exactly the same gas composition, which means for 1000° C about 30% carbon dioxide and 70% carbon monoxide, if no nitrogen enters the pot. The fresh ore mixtures are mainly within the range 14–22% of oxygen. The used ore mixtures in the range 12–16% of oxygen include the spent ores mentioned by Bernstein and by Webster and Probst. Those of Bowden's ore mixtures which produced peeling had an oxygen content of 3–9%, but even these should have the same gas composition in equilibrium, like all the other ore mixtures. Gas compositions as chosen by Preece and Irvine, with 75, 80, 85, 90, and 95% of carbon monoxide, would lie in the region where the curves bend upwards, indicating that here iron with a certain dissolved content of oxygen has been in equilibrium with the gas composition. As long as FeO and

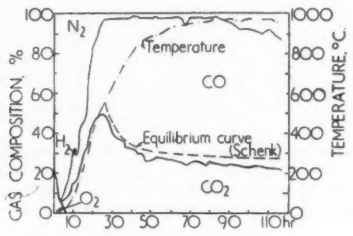


Fig. B—Gas composition and temperature in an annealing can (Oberhoffer and Zingg)

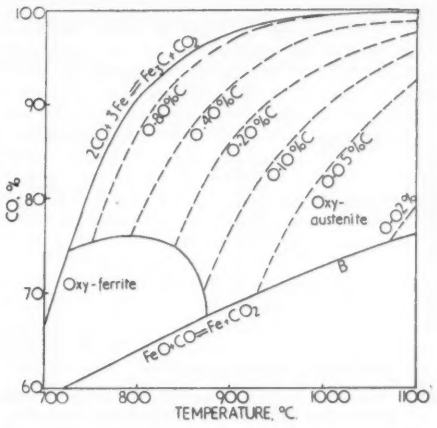


Fig. C—Iron–carbon–oxygen equilibrium; CO + CO_2 = 1 atm (Johannsen and van Seth)

this saturated solution of oxygen in metallic iron are coexisting, there should theoretically always be the same gas composition.

In regard to the gas composition actually found in annealing pots, the results of Oberhoffer and Zingg are presented in Fig. B. They analysed the gas which actually develops inside the annealing pot during heating up and after the temperature has been reached. Originally a large amount of nitrogen was present from the air in the inter-spaces of the ore mixture. On heating up, this is driven out, and before the full temperature inside the pot has been reached we find high carbon dioxide and carbon monoxide contents. The equilibrium curve for CO_2, calculated from the analysed CO contents, is very near to the curve which is actually found as the average CO_2 content of the gas inside the annealing pot, the carbon dioxide always being a little lower than it theoretically should be. Similar tests have been made by Schüz and Stotz with the same result.

Figure C shows the influence of gas composition on the carbon content of the austenite. With gas mixtures of higher carbon dioxide contents we should get lower carbon contents. That is well known ; and remembering Fig. A, where a certain amount of oxygen was dissolved in the solid solution, we conclude that we should have lines for dissolved oxygen as well, similar to those for residual-carbon contents. We do not know the exact position of these lines, but only their main direction.

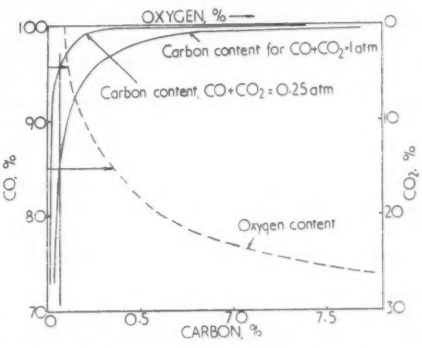


Fig. D—Equilibrium composition of iron annealed in CO–CO_2 at 1000° C

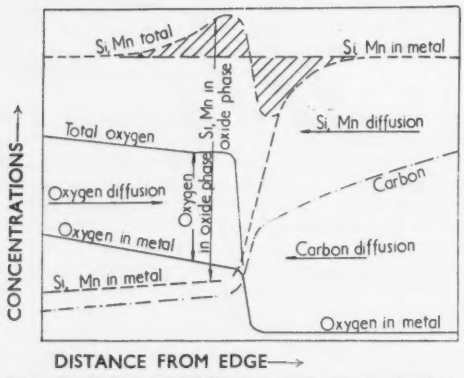


Fig. E—Schematic diagram of concentration gradients in peel and adjoining metal

We know that with higher temperature the dissolved oxygen content should be higher, and with lower carbon content it should also be higher.

In Fig. D I have tried to give a schematic picture of how carbon content and oxygen content would be interconnected inside this solid solution. Two curves for the carbon content in austenite are shown, one applying where the sum of partial pressures of $CO + CO_2$ equals 1 atm and the other where the sum of partial pressures of $CO + CO_2$ equals $\frac{1}{4}$ atm. Whereas the equilibrium lines for dissolved carbon in austenite depend on the total pressure of $CO + CO_2$, the equilibrium curves for the oxygen content in solid solution would be independent of this sum of pressures, so there is only one curve for oxygen content dissolved in austenite.

To establish a certain low carbon content in austenite, oxygen has to be introduced to it, and to come to one definite final carbon content, less oxygen will be needed if the total pressure of $CO + CO_2$ is smaller than 1 atm. That is indicated in Fig. D by the vertical line on the left and the two horizontal lines which come over to the oxygen-content curve. I have not given any scale for the oxygen curve because I do not know the exact figures for it.

Figure E gives some idea of what actually happens when decarburizing with a $CO + CO_2$ mixture. From Fig. D we know that to achieve a low carbon content a certain oxygen content should be dissolved in the metal, but this will be possible only after silicon, a very strong deoxidizer, has been practically burned to SiO_2. That means that up to a certain depth we may have an increased oxygen content in the metal, leaving only a small proportion of the original silicon content in solution, the remainder having been burned to SiO_2.

The same will happen to manganese, but to a different extent, because the affinity of manganese for oxygen is less than that of silicon, so that the residual content of manganese in the metal would be somewhat higher. Under these conditions, we shall obtain a low carbon content in the oxygen-rich region, and some migration of carbon from the core of the casting into the outer layer will occur. However, if we now draw a curve for silicon or manganese dissolved in the metal we find a low content of both of these in the outer layer and a high content in the core of the material which has not been oxidized and where the oxygen content is still the original value from the melt; owing to this concentration gradient, it may be expected that both metals will start to diffuse outwards into the oxidized layer, where again they will be picked up by oxygen and transformed into oxides.

I think that by such a process we can expect to get a certain minimum for the total concentrations of silicon and manganese (metal + oxide) behind the inner rim of the oxidized layer and a certain maximum higher than the original contents of both just near the inner boundary of the oxidized layers.

So far, I have dealt only with a metal containing

Fig. F—Edge of casting, showing preferential oxidation about 0·6 mm deep, and practically uniform sulphide distribution in the metal and the inner half of the oxidized layer × 60

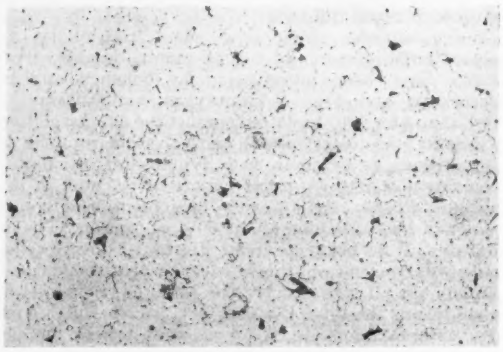


Fig. G—Centre of casting, showing a small amount of pearlite and numerous sulphide inclusions × 60

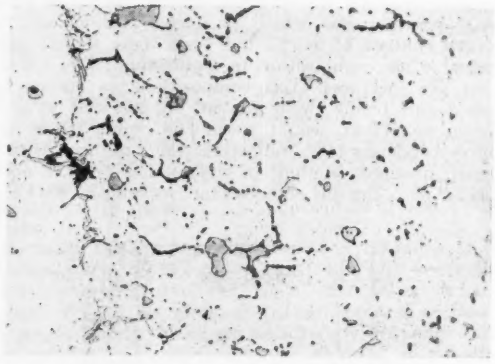


Fig. H—Edge of casting, showing fayalite in the outer half of the oxidized layer, fayalite and manganese sulphide in the inner half of this layer, and some coarse pearlite at the boundary to the round metal × 600

Figs. F–H—Photomicrographs of a casting with 0·5-in. wall thickness, annealed for about 2000 hr in about 50 annealing cycles in a gas-malleablizing furnace

carbon, silicon, manganese, and oxygen. The conditions become very complicated if sulphur also is introduced. We do not know very much about what happens under such conditions, but we may draw some conclusions from these former considerations. I should imagine that even if there is no sulphurization, but simply an atmosphere which does not take sulphur away, we should still get a migration of sulphur on lines similar to those for manganese and silicon. Normally, whiteheart malleable iron may be considered as a saturated solution of sulphide in iron with some free sulphides in addition.

In the outer oxidized layer there are not only the metal phase and the oxide–silicate phase, but at first, perhaps, still some sulphide as well. This sulphide, which is partly dissolved in metal and partly present as a separate phase, will now be distributed on the oxide–silicate phase and the metal phase, on similar lines to the distribution which is obtained between metal bath and slag in melting processes. The oxide–silicate phase will be able to dissolve quite a quantity of sulphur, thus lowering the sulphur concentration in solution in the metal, and creating a concentration gradient from core to surface; some of the sulphur in the core will then start moving outwards and will be collected nearer the interface between the sound metal and the oxidized layer.

I imagine that, depending on the original content of silicon and manganese, the ability of the silicate phase to dissolve sulphur will vary. Irons of comparatively high manganese content will contain a silicate rather high in manganese, and this will be able to dissolve more sulphur than one which consists only of FeO and SiO_2. Moreover, if the original manganese is high enough, all sulphide will be in the form of MnS, but on account of the combustion of manganese in the oxidized layer it may be that the metal concentration of manganese in iron will become so low that this MnS will be reconverted into FeS and then be free and able to move. It seems possible that on these lines a maximum of total sulphur content is built up just on the inner rim of the oxidized layer; even if we do not work with sulphurizing conditions in the beginning and desulphurizing conditions at a later stage of the annealing cycle, we may still get that sulphur-distribution curve which we know is found in our castings at the end.

From the work of Preece and Irvine, as well as from that of Bernstein, I think we can be sure that the presence of some liquid phases will be mainly responsible for the great acceleration of the oxidizing process; and I believe that sulphur is one of the causes of lowering the melting point of these oxide, silicate, and sulphide phases to the point where they are liquid at the annealing temperature. One conclusion from that would be that if the decarburization process is carried out at such a low temperature as to avoid the liquid phase we should get quite a different picture of the peel. I wonder whether anything has been done in this direction?

I think it is generally agreed that under clearly desulphurizing conditions no peel (in the current sense) is developed, and partial oxidation is taking place at a much lower speed than with the sulphur accumulation present in the oxidized layer. A few days ago I saw a very nice example of that: a casting with a 0·5-in. wall thickness had been annealed about 50 times in gas atmosphere for approximately 40 hr each time, amounting to about 2000 hr at 1050° C. The fracture of this casting showed no peel, which I think is a very good confirmation of our opinion that with desulphurization during the annealing time no peel can be built up.

By courtesy of Mr. Palmer, of the British Cast Iron Research Association, I am able to show some photomicrographs of this casting (Figs. F–H) which reveal preferential oxidation up to a depth of 0·6 mm, which is very little for an annealing time of approximately 2000 hr. Whereas the outer half of this oxidized layer is practically free from sulphide inclusions, some manganese sulphide inclusions are seen at the inner rim as well as in the sound metal behind it, and no appreciable sulphide accumulation is apparent.

On bending, this thin oxidized layer does not break loose, and I think for all practical purposes it can be said that on annealing in gas atmosphere no peel in the commonly accepted sense is formed.

Mr. **A. J. Nicol Smith** (Ministry of Supply): One difference in the papers that has not yet been brought out is the effect of high temperatures. Bernstein advances the opinion that peel increases with temperature, while Bowden finds a different structure, at least in silico-manganese steels. I feel sure that he will agree that he has found similar brittle structures in malleable iron. Mr. Humfrey, in fact, mentions brittle structures in his introduction. This discrepancy between the papers is difficult to explain in terms of any of the theories of peel, but I feel that account must be taken of it before we can arrive at a completely satisfactory solution of the problem.

Turning to the question of oxidation and reduction, I consider that these are relative terms. The quantity of SO_2 present must influence the critical limit of CO_2. I do not think there is a great anomaly between results showing peel with 10% of CO_2 and 0·1% of SO_2 on the one hand and with 20% of CO_2 and 1·0% of SO_2 on the other.

Bernstein's figures (page 21) for his annealing ore mixture seem to me rather improbable. I should have expected a much higher content of Fe_2O_3. A general point in this connection is that analysis of the ore after the anneal is likely to be at least as important as before and to give a better idea of the probable gas concentrations in the final stages.

Bowden's paper contains the suggestion that there exists in the peeled layer an iron sulphide with excess sulphur present. The super-lattice was, of course, found in the cold. At high temperatures the mixture could be regarded as FeS with excess sulphur in solution. This may help to explain peel. Excess sulphur at the inner face of the sulphide layer would react with iron to form sulphide. This provides a possible explanation of the building up and moving inward of the sulphide layer. It remains to explain how the excess sulphur gets into the sulphide at the outer boundary of the layer. In the presence of reducing agents—carbon, carbon monoxide, iron, and silicon may all be present—and with the possibilities of catalytic activity at the various surfaces, it is not too much to suppose that the sulphur gases present, *e.g.*, SO_2, could be reduced to sulphur. In this connection it must be remembered that the gas conditions close to the casting and in the disrupted grain boundaries of the casting surface are not necessarily the same as the average of the annealing pot.

I do not feel altogether happy about Bowden's equations. We are discussing the decarburizing of iron, yet equation (1) produces iron carbide. We are explaining how iron sulphide gets in, yet equation (2) decomposes this compound. There would seem to be no difficulty about accepting fayalite. Silicates are quite commonly produced by the oxidation of iron and silicon.

Bernstein's list of factors producing peel (page 32) contains two items, (6) and (7), the silicon content and the initial carbon content of the metal, which might be bound up with the decarburization of the surface layer. Bernstein does not seem to believe that silicon promotes decarburization. His final statement at the end of the

paper, that if silicon causes graphitization it will decrease decarburization, is probably true. We are here, however, dealing with carbon in solution and are considering the formation of a low-carbon surface zone. Experiments in the heat-treatment of silico-manganese steel have shown that decarburization increases with higher silicon content.

Mr. **D. M. Dovey** (General Electric Co., Ltd.): Preece and Irvine, in their paper on sulphide penetration, show very beautifully that the sulphide eutectic is driven through the iron mainly by diffusion of carbon. It would be expected, then, that the same laws would govern this progression as those which govern carbon penetration; that is, the penetration curve should be parabolic, and an increasing temperature or an increasing carburizing potential of atmosphere should increase the penetration rate. Preece and Irvine found that the penetration rate was almost independent of temperature and they state that this is due to the uptake of carbon from the monoxide approaching a maximum value. This statement *alone* would not explain the facts observed, for, if the amount of carbon uptake is constant with increasing temperature, nevertheless carbon atoms will arrive more rapidly at the sulphide film owing to the increased speed of diffusion. Hence the explanation, if it depends only upon carbon uptake, must be that less carbon is being taken into the surface at the higher temperature than at the lower.

With reference to the oxide–sulphide coatings reported on page 340, it would be interesting to know whether the penetrating oxide–sulphide layer, formed at some fixed concentration of carbon dioxide below 15%, slowly lost oxygen when treated in a carburizing atmosphere.

With respect to the influence of manganese, silicon, and sulphur, it is probable that the liquid phase is preceded by a region wherein there is a concentration gradient of sulphur from the band inwards. Any available manganese in front of the advancing eutectic would act as a sulphur-remover in the solid phase; if the sulphur removed in this way, as manganese sulphide, did not re-dissolve in the eutectic on the latter's approach, then the effect of the manganese would be to increase the iron/sulphur ratio in the eutectic and to offset to some degree the effect of the advancing carbon on the other side. One would expect, then, to see manganese sulphide particles in front of the iron sulphide eutectic whenever free manganese is available.

If we may postulate that manganese removes sulphur from a region preceding the band, could not silicon remove oxygen in the same way, when the advancing band contains oxide? Preece and Irvine have demonstrated that oxygen can diffuse to an iron sulphide particle from the surface of iron, treated in 75% CO/25% CO_2, in what appear to be times of similar duration to those required to drive the sulphide in by carbon diffusion. It is important that a comparison be made between the lengths of time in the two cases since the diffusion constant of oxygen in iron is accepted as being approximately 10^{-3} times that of carbon. If oxygen diffusion were of the same order as that of carbon in this case, then the possibility of the diffusion of oxygen causing progression of the band might be considered. The same authors made use of highly carburizing atmospheres and found that silicon decreased penetration in iron, but Bernstein treated cast iron in ore and found that silicon increased the peeled layer. The difference must be bound up, in some way, with the oxidation of the silicon.

One would expect sulphur in solid solution to increase the speed of advance of the eutectic since its effect would be the opposite to that of available manganese. There is, then, the possibility that "available" concentrations of manganese, silicon, and sulphur on the inside of the band influence the rate of penetration of the eutectic by the extent to which they oppose or augment the pressure of the dissolved carbon on the outside of the band. If so, in the case of manganese and silicon the extent of their influence will depend upon the rate of diffusion of each up to the band. Presumably, when the carburized case becomes sufficiently deep, the rate of diffusion of carbon slows down to an amount which is nullified by the opposing diffusion of either silicon or manganese and progression of the band ceases.

The oxidation of a deep-seated sulphide film in an atmosphere of 75% carbon monoxide and 25% carbon dioxide is very interesting. If sulphur and oxygen had no mutual interference effect in solid solution, one would have expected only that the sulphide would disappear slowly as the sulphur dissolved and migrated to the surface, where desulphurization would be taking place. When all the sulphur had migrated to the surface, did the iron oxide slowly disappear? Does not the evidence favour the view that dissolved sulphur represses rather than increases the solubility of oxygen?

The general conclusions reached by Preece and Irvine are undeniable, but, with reference to the embrittlement of steels in atmospheres of low oxygen-pressure, it may be that the embrittlement is due either to the precipitation of an oxide of low solubility or to the precipitation of oxide caused by the lowering of the solubility of oxygen by other elements in solution.

Referring to the paper on peeling by the same authors, they mention the occurrence of segregation of carbon. Did this occur on cooling slowly? I believe that this type of segregation on slow cooling has been observed in welded steels where oxygen is absorbed during welding.

On page 6 reference is made to various light scales appearing in different atmospheres. Was the type of scale formed independent of the carbon diffusing to the surface? That is, was it independent of the time of treatment?

The stated composition of the gas atmospheres used throughout these experiments may give an erroneous impression of the state in which the sulphur is present at elevated temperatures in the gas phase. One cannot assume that the production of carbonyl sulphide by the reaction:

$$SO_2 + 3CO \rightleftharpoons COS + 2CO_2$$

may be neglected. If it is appreciable, the effective concentration of sulphur dioxide is reduced, and I suggest that the authors give this point some consideration.

I should appreciate some comments on the following possibilities: First, that sulphur and oxygen reduce each other's solubility in iron; secondly, that the formation of carbonyl sulphide must be allowed for in the determination of the sulphur pressure of the atmosphere; thirdly, that the thin layer of scale which is obtained on iron (Preece and Irvine, page 6) consists of FeO and FeS in amounts controlled by the oxygen pressure, which will be governed by the CO_2/CO ratio, by the sulphur pressure and by the mutual effect of sulphur and oxygen on the solubility of each other; and fourthly, that at low concentrations of carbon dioxide there may be an inversion of the "sulphur-pressure" curve owing to the carbonyl sulphide reaction, and that, except when this condition obtains, the "sulphur pressure" of the atmosphere will be given by the equation:

$$S_{Fe} = \frac{K_2.(CO)^2.(SO_2)_{Initial}}{[(CO)^2.K_1 + (CO_2)^2]}$$

It appears that carbon monoxide will be both desulphurizing and carburizing, the carburizing being by

far the more rapid process. Since carbon and sulphur reduce the diffusion constant of one another in solid solution the rate of diffusion of the sulphur to the surface from an inner eutectic band will be reduced in the presence of dissolved carbon and there will be very little sulphur lost by removal at the surface.

With reference to Bowden's paper, the presence of fayalite is an important point, but it has not been definitely established as an essential part of the process. Admittedly silicon would form a sub-scale prior to iron oxide formation in the presence of low quantities of dissolved oxygen ; however, the effect of silicon appears to call for further investigation.

In the paper by Webster and Probst some very interesting facts are given on the depreciation of the peeling with the decline of sulphur content of the ore, thus confirming the dependence of sulphur pressure on the sulphur dioxide concentration.

An interesting point in Bernstein's paper is the very marked difference in carbon concentration as against what would be expected if the sulphide or oxy-sulphide phase was being driven in by carbon uptake. On those grounds I think that there may be some other mechanism possible. In general the gas mixtures used by Bernstein have not been strongly carburizing. The author brings out very well the necessity for initial decarburization prior to peeling, and states that an increase in sulphur dioxide concentration will increase the sulphide present, but it is not obvious that it is necessary to have a carburizing atmosphere in the later stages to produce this effect of "peeling." If carburization is not an absolute necessity, what is the alternative driving mechanism ? In Bernstein's paper and in the papers on works investigations the effect of oxygen on the formation of "peel" is marked. However, the production of a eutectic in depth could not be brought about rapidly unless, as a first essential, the driving element had a speed of diffusion through the metal comparable with that of carbon.

Mr. **K. J. Irvine** (Leeds University), in reply, said : Before I attempt to deal with the points which have been raised there are a few which I should like to make myself with regard to the other papers. They all emphasize the influence of high sulphur ore, and that is most important. They agree also that there are indications that substantial decarburization is essential to peel formation, and there is an indication in at least one of the papers that a weak annealing atmosphere is a contributory factor. These statements all confirm results which we have obtained when using synthetic atmospheres.

At the risk of repetition I should like to emphasize that there are different surface defects which can be obtained. It is possible to get intercrystalline oxidation alone, and intercrystalline oxidation plus sulphide. I feel that these are the structures which Bernstein obtained, and they are the structures which we obtained in a constant atmosphere. It is also possible to get a zone of intercrystalline oxidation at the surface with a definite band of iron sulphide at the inner limit of this zone, which is what we have called the peeled structure and is the one which we primarily investigated.

It is possible for both the first and second types to occur under special conditions, but we should like to emphasize again our statement that the third type of structure, with the band of iron sulphide at the inner limit of the zone of intercrystalline oxidation, can occur only under the conditions indicated in our paper, namely, where the atmosphere changes and becomes carburizing.

Bernstein's experiments with varying compositions of iron are interesting, because the British Cast Iron Research Association supplied us with irons of identical composition, and we carried out experiments both in constant atmospheres and in the atmosphere cycle described in the paper, and in general they confirm completely the results obtained by Bernstein ; that is, in general, silicon increases the effect and manganese tends to decrease it.

We believe that the important factor is the ratio of manganese to silicon and not of manganese to sulphur. I would almost go so far as to say that the ratio of manganese to sulphur has no effect. Another interesting point is that whether or not manganese sulphide is present does not affect the penetration of sulphur under carburizing conditions ; it affects the rate of penetration, but does not stop it. It has often been stated that if high manganese is present manganese sulphide will be formed and penetration will not take place because manganese sulphide has a high melting point, but the sulphide which forms is molten at 1000° C and moves readily at that temperature.

Could Mr. Bernstein give any explanation of the results shown in item (3) of his summary of results (page 29), where he says that no effect was obtained with a series having 0·55% of silicon and varying manganese ? He states that no peeling was obtained in any of these instances, but surely this does not agree with other results in his paper. Might it not indicate that his experimental conditions were varying in his experiments ?

I do not agree with conclusion (2) on page 32, where it is stated that by increasing the manganese content relative to the sulphur content it is possible "completely to inhibit peeling." This is not supported by the results shown in his paper, and indeed the author modifies it later (page 36) when he says that manganese cannot be relied on for the certain prevention of peeling.

Turning now to the experiments in gaseous atmospheres, I should like to refer back to my definition of a peeled structure—that is, a zone of intercrystalline oxidation and a definite band of sulphide at the inner limit of this structure—and ask Mr. Bernstein whether this is the structure to which he refers, because on no occasion did we obtain this structure when the atmosphere was constant, though we did obtain a structure with intercrystalline oxidation with sulphide associated with the oxide in sulphur-containing atmospheres with less than 10% of CO_2.

The experiments described by Bernstein are very similar to those with constant atmospheres described on page 5 of our paper, and the essential difference between those and the reactions leading to the peeled structure can be seen from Bernstein's Figs. 25 and 29. Figure 29 shows a distribution of sulphur such as would be expected from a continuous diffusion of sulphur inwards, which is very different from Fig. 25. The very difference between Figs. 25 and 29, I think, shows that the experiments which he carried out in constant atmospheres were not repeating the conditions leading to peeled structure. The explanation given, namely, that the distribution of Fig. 29 is changed to the distribution of Fig. 25 by desulphurization during the latter part of the process, seems unlikely. Such a mechanism as we have described in our paper, however, would change the distribution shown in Fig. 29 to something similar to that shown in Fig. 25. If this mechanism is accepted, much of the further discussion which follows these illustrations is rendered unnecessary. It is on this point that I think the big difference between our two papers exists, and I should be very interested to hear Mr. Bernstein's comments on it.

In reply to Mr. Jenkins, the carbon content of the Armco iron was about 0·03%. The illustrations in our paper show a very slight amount of carbon beyond the

sulphide band, and we have said in the paper (page 338) : "As the depth of penetration increased, the sulphide layer became less definite, tending to split up into separate particles." That is due, I think, to the effect of the carbon beyond it.

With regard to the experiments from 1000° to 1200° C, we also were surprised at the results. We have not as yet investigated this matter thoroughly, but an important difference has to be borne in mind when considering these experiments and those on normal carburization with increasing temperature : the carbon distribution from the surface to the sulphide band is practically constant at a eutectoid composition. If penetration curves are examined for ordinary carburization it will be found that the amount (not the concentration) of carbon is roughly the same as the temperature increases.

We changed our atmosphere because various published work reported changes in atmosphere during annealing. It appeared from the spent-ore analyses that reduction had gone on to a remarkable extent ; Bowden reported quite high concentrations of iron. I think it is fairly definite that in these cases the atmosphere does become carburizing. Below 15% of carbon dioxide very slight amounts of carbon were visible at the edge. The amount did not increase much until the CO_2 content of the atmosphere changed to about 2½%, when the carburization increased very rapidly, and sulphide penetration also increased very rapidly at the same time.

Mr. Jenkins wonders whether sulphur can be effective. There are experiments reported in these papers where the penetration has been brought about by atmospheres not containing sulphur, and in every case it has been associated with carburization ; that is, the penetration of carbon. As Mr. Preece said in introducing this paper, it is part of wider work, and we took out these experiments because we thought that they might be of assistance in the discussion. We felt that no one had even indicated how sulphur could possibly move in. I do not want to go any further into these experiments, but it is interesting that similar effects (*i.e.*, sulphur moving into iron) are noticed with hydrogen, nitrogen, and carbon, which it will be noted are interstitial elements ; similar penetration can be obtained with these gases into nickel, which also forms interstitial compounds, indicating that the penetration is due to an interstitial element. For that reason I would not agree with the theory which was advanced about oxygen, or with what Mr. Jenkins said about sulphur. You can produce almost exactly the same thing with nitrogen and hydrogen, as probably Mr. Bernstein will agree ; but I think that it is limited to those. It is a special case of an effect due to an interstitial element.

Mr. **J. S. Bowden** (Tin Research Institute) : I do not think it advisable to specify an upper limit for the sulphur content of the ore, because there is always a tendency to move towards that upper limit. In any case the average sulphur content of the new ore was not particularly important because the spent ores invariably contained more sulphur than any new annealing ores that were supplied.

Riff ores are described in a report* issued by the Department of Scientific and Industrial Research in 1918. Several ore beds have been developed. In some places the sulphur content increases as the ore goes to depth, the hematite changing to magnetite which is contaminated with pyrites and calcite. In other areas the deposits contain a high-grade manganiferous hematite and the Riff mines have yielded considerable quantities of rich low-sulphur hematite. It would be inadvisable to condemn all Riff ores on account of one bad consignment.

In reply to Mr. Bernstein and Mr. Nicol Smith, the term "super-lattice" was used by Rooney at the National Physical Laboratory, and I assume that he means that some additional sulphur is present in the lattice.

The investigations reported in the two papers by Preece and Irvine have cleared up most of the problems connected with peeling in whiteheart and with exfoliation in case-hardened components. Whilst, however, I am in full agreement with their finding that peel formation requires a very high CO/CO_2 ratio in the malleablizing atmosphere, I feel that their simple method of prevention, by the use of ore mixtures containing adequate proportions of ferric oxide, does not quite meet all the circumstances. Most ore mixtures contain plenty of new ore, but some of them become unduly impoverished during the anneal by reaction with carbon from the castings and with furnace gases which diffuse into the pots. In all works there is a natural desire to save fuel, and some try to achieve this object by damping down the fires and closing the oven flues as soon as the charge has reached malleablizing temperatures. Others leave a long smoky flame to curl around the inside of a closed oven and endeavour to prolong the life of annealing pots by avoiding oxidizing conditions. Excess of zeal in these directions results in an accumulation of carbon monoxide inside the oven and so helps to set up the conditions in which peeling can take place.

Since all the investigators agree that peeling does not take place until the castings are partially decarburized, I would suggest that the phrase used by Preece and Irvine should be amplified to some extent, to emphasize that the ore mixture should contain adequate proportions of oxides of iron throughout the whole of the malleablizing cycle.

The fact that furnace gases diffuse into the pots and may have a pronounced influence on the annealing ore does not seem to be generally appreciated by annealers. Over a fairly long period Dr. Norbury and I found that certain ovens delivered a spent ore which gave a fairly consistent analysis of about 60% metallic iron and 20–25% iron oxides, with a sulphur content of about 0·65–0·70%. When these spent ores, without additions of new ore, were used to malleablize scrap castings in ovens where more oxidizing conditions prevailed, most of the metallic iron was converted to oxide and the sulphur content was reduced to as low as 0·35%. This suggests that the ore acts partly as a buffer between the castings and the oven atmosphere.

Bernstein considers that sulphur in the annealing ore is the primary cause of peeling, but I must point out that all hematite ores and spent ores contain sulphur, and that all ores would pick up a certain amount of sulphur from the products of combustion which pass through the oven. As a matter of fact, the spent ore from the pans which produced the peeled cruciform grids referred to on page 13, contained less than 0·10% of sulphur but about 80% of metallic iron. We had noticed that the spent ore on this particular plant was becoming progressively weaker and, anticipating peeling troubles, had arranged to collect samples and examine the castings when the ovens were emptied.

Many of the older men in the malleable industry sprinkle a handful of sal ammoniac into each barrow-load of spent ore as they make up their annealing ore mixtures, and claim that this addition eliminates the risk of peeling troubles. Their products seem singularly free from peel, probably because they usually employ fairly strong ore

* Report on the Sources and Production of Iron and Other Metalliferous Ores Used in the Iron and Steel Industry. London, 1918 : H.M. Stationery Office.

mixtures ; but the volatile chloride may prevent the formation of the oxide–sulphide scale. I wonder whether Mr. Webster or Mr. Bernstein can give us any information on the functions of NH_4Cl in malleablizing.

I am looking forward to the further reports promised by Preece and Irvine, and I am particularly interested in their suggestion (page 343) that similar processes may operate in the embrittlement of steel on heating in atmospheres of low oxygen pressure.

During the war we found that a considerable number of whiteheart malleable castings were exceedingly brittle. All these castings had been annealed in plants which were experiencing peeling troubles, to a greater or less extent, and all the ovens were delivering an abnormally weak spent ore. Fortunately, however, the firms producing peeled castings were not invariably in trouble with embrittlement ; the defect was, as a general rule, confined to the thin, well-decarburized sections of castings ; but in several instances it was observed in cross-sections exceeding 0·5 in. The fracture was always very bright and coarse-grained, and micro-examination showed an almost completely ferritic structure with an abnormally large grain-size, particularly just below the surface of the casting. In some cases there was evidence of intercrystalline sulphide penetration and a suggestion of carbide near the crystal boundaries with, perhaps, a trace of peel or an irregular, ill-defined, subcutaneous band of sulphide with the usual silicates and oxide.

Analysis of brittle castings, and the experiments in which irons of various compositions were malleablized under different conditions, showed that a metal with a high sulphur/manganese ratio ($S > Mn/1 \cdot 7$) was particularly prone to grain growth, the grain-size at any given temperature increasing as the excess sulphur content increased, and the largest crystals being formed in the hottest parts of the ovens.

We were unable to find a satisfactory explanation of this embrittlement in a material which will normally withstand a considerable amount of deformation. It could not be attributed solely to the large grain-size, as equally coarse material was quite malleable. We considered that there seemed to be some sort of connection with peeling. We were able to reclaim most of the suspect castings and to refine the grain-size by re-annealing through an ordinary malleablizing cycle, or, where facilities were available, by quenching from about 1025° C.

In another series of experiments, carried out in oil-fired heat-treatment furnaces, pieces of $\frac{7}{16}$-in. dia silicon–manganese spring steel rod (STA 2(*b*)) were heated at temperatures of 900°, 950°, and 1000° C, for 5, 15, and 30 min. In each experiment some specimens were heated in air and others in sealed tubes containing either powdered charcoal or a mixture of powdered charcoal and ferrous sulphide. All the specimens were allowed to cool in still air. No peel was produced in these experiments, which were carried out to determine whether heating in a high concentration of carbon monoxide would produce embrittlement similar to that observed in the malleablized silicon–manganese steel.

All the specimens heated in the normal furnace atmosphere were tough and ductile, withstanding three blows in a 120-ft.lb. Charpy machine on 4-in. centres without fracture, and bending through at least 85° during the tests. The specimens which had been heated in the tubes were all embrittled, and the impact strength of the unnotched bars had fallen to as little as 42 ft.lb. with only 1° bend. This was not a surface effect as rods from which 0·030 in. had been machined were still brittle.

When rods were heated with half their length inside tubes containing powdered charcoal and the other half projecting through a fireclay seal into the furnace atmosphere, the embrittlement was confined to those portions which had been in the higher concentrations of carbon monoxide. Reheating for $\frac{1}{2}$ hr at 950° C in the ordinary furnace atmosphere restored the toughness. We did not find any unusual features in the microstructures of the embrittled steels. I hope that Preece and Irvine will be able to solve the problem as their work proceeds.

I agree with Preece and Irvine, and with Jenkins, that the gaseous malleablizing process will be free from peeling troubles, but only so far as the atmosphere is controlled within the required limits. Automatic controllers have been known to go wrong, and some interesting structures can be seen in, or near, reduced scale.

Mr. **G. R. Webster** (Britannia Iron and Steel Works, Ltd.) : Our paper gives the results of rather quick practical works experiments carried out at a very urgent time during the War, some four or five years ago, when peeling had developed very dangerously and had made the finding of a solution so vital to the war effort. We carried out experiments to measure the volume of, and to analyse the gases from, a sealed steel malleablizing pot during the process, and the figures we then obtained have now been confirmed by Dr. Schulte.

Mr. **A. E. Probst** (Britannia Iron and Steel Works, Ltd.), in reply, said : If I had known at the time that other people were putting such a lot of research work into this problem, we should not have made our experiments. Nevertheless, I am pleased to note the similarity between the results obtained by Bernstein and our practical experiments. I must admit that I still cannot understand why, with a very weak ore mixture, peeling should not take place if a lot of sulphur is present in the ore. This is contradictory to the results of the experiments which we have carried out in a fairly modern annealing furnace. I suppose that some of the data put forward by Bowden concern very old-fashioned annealing furnaces, and he rather suggests that the furnace atmosphere had some influence on the peeling. In our case I can state quite definitely that the furnace atmosphere had no effect on peeling.

In reply to Mr. Peace I confirm that the volatile sulphur was obtained by treatment of the ore with acid.

Mr. Jenkins doubts the statement that carbon dioxide is a reducing agent. I can neither confirm nor deny it ; I took that statement from the literature.

Mr. **J. Bernstein** (British Cast Iron Research Association), in reply, said : Mr. Humfrey's introduction takes note of a certain conclusion of Preece and Irvine with which I cannot agree. I would like to emphasize that the most important factor in peeling is the sulphur content of the ore or the annealing atmosphere, and that the carbon monoxide content of the atmosphere is of relatively minor importance. I prefer the term " decarburizing " in place of " oxidizing " when talking about the annealing of whiteheart malleable iron, because it is possible to decarburize in what one would normally expect to be a reducing atmosphere, *e.g.*, dry hydrogen.

It has been stated that the important gases in the peeling process are carbon dioxide, carbon monoxide, nitrogen, and any sulphur-containing gases, but no mention was made of water vapour which is, as far as my experience goes, even more strongly decarburizing than carbon dioxide, and will always be present in commercial annealing practice. While mentioning that, I would suggest that the gases obtained by Preece and Irvine were not very dry if they passed only through the apparatus shown in their Fig. 1, page 4. Calcium chloride is not a very effective desiccant ; phosphorus pentoxide

is more effective. For that reason I feel that some of their CO_2 figures would produce more decarburization than dry CO_2 of the same figure.

The main point of disagreement between the papers appears to be the influence of the carbon monoxide and carbon dioxide contents of the annealing atmosphere. Mr. Jenkins' equations involving partial pressures show that the penetration of sulphur depends upon the partial pressures of sulphur and carbon dioxide in the atmosphere ; I agree with his views. I also agree with the results produced by Preece and Irvine, but I do not entirely agree with their conclusions. The apparent divergence of our opinions is perhaps due to the fact that we have been working with different sulphur contents in our annealing atmospheres and that we have possibly derived different conclusions from what are really complementary results. I will not elaborate on this point other than to say that I believe that the two papers together probably contain all the information required for a satisfactory explanation of peel formation, provided of course that the influence of the relative partial pressures of the reactants is not overlooked. It is possible both to increase and to decrease peeling by increasing the ore strength ; it depends entirely upon the sulphur content of the ore. Experience obtained since these papers were published has shown that even where certain firms are temporarily overcoming peeling by increasing the strength of their ore they are still running into peeling. This is due to excessive sulphur in the annealing ore being offset by adding new ore of low sulphur content. Unfortunately, further sulphur is being absorbed by the ore from the annealing atmosphere and thus in spite of the use of a stronger ore mixture peeling is still taking place.

The main influence of the decarburizing power of the atmosphere is in the depth of penetration of the peel. I feel that the depth of the peeled layer is dependent upon a certain carbon content in the iron. I did not refer to it specifically in my paper because the actual value of this carbon content will depend upon the composition of the metal with respect to manganese, sulphur, and silicon. It is not possible to be specific about a minimum carbon content unless account is taken of these other elements.

I do not agree with Mr. Bowden on the effect of manganese, because I have found that peeling can be produced in irons with higher manganese and higher silicon contents than his manganese steel, but with lower carbon than is normal in white irons, and I am sure that the carbon in Bowden's steel was lower still. That brings us to the point made in my paper that carbon itself has an influence on peeling. It would appear that carbon in iron tends to inhibit penetration of sulphur under certain conditions. Although the study of materials differing in composition from commercial whiteheart is most important in the study of a problem of this kind, the conclusions drawn from such experiments should not lose sight of the influence of the amounts of particular elements in the main material under investigation. For this reason I still maintain that increasing the manganese content will reduce peeling in normal commercial whiteheart malleable iron and that the manganese/sulphur ratio itself has an appreciable effect within this range of irons.

I would like now to present some experimental evidence obtained from work completed after my paper was submitted for publication. Annealing white iron in atmospheres consisting of pure, dry, carbon monoxide may result in some decarburization of the material and a small amount of desulphurization of the surface layers. The addition of 1% of sulphur dioxide to such an atmosphere results in slightly more decarburization and a sulphurizing effect. The sulphur content of the metal is at a maximum at the surface, decreasing towards the centre of the section until it reaches the original sulphur content of the metal. This form of penetration of iron sulphide is not that which is observed in peeled samples. Similar results, under the same conditions, were obtained with pure, dry hydrogen ; a smaller decarburizing effect but an almost equal desulphurizing effect resulted from annealing white iron in this gas. When sulphur dioxide was added to the hydrogen more decarburization was effected and some sulphur penetration occurred. However, when dry hydrogen sulphide was added to the dry hydrogen no decarburization was apparent but extensive sulphur penetration occurred—the most extensive sulphide penetration that had been obtained in any other experiments. Again the form of the sulphide was not that encountered in peeled samples and there was no oxide present. The addition of less than 1% of water vapour to that atmosphere increased the amount of decarburization, and peeling resulted. The presence of an oxide phase was not detected in the peeled layer and, apart from this, the structure was typical of a commercial peeled sample. The experiments with hydrogen were carried out because it was felt—and this is still my feeling—that the penetration of sulphur as sulphide in the form which we recognize as peeling is not necessarily consequent upon the presence of a silicate phase or any other oxide phase ; rather would I say that the presence of the oxide phase may be consequent upon the presence of the sulphur which has diffused inwards as sulphide. In addition, these further experiments demonstrate that more pronounced penetration of sulphur may occur when the atmosphere is less strongly decarburizing. This tends to confirm the importance of the influence of partial pressures. It also confirms the work of Preece and Irvine who found that sulphur penetration occurred more noticeably in atmospheres richer in carbon monoxide. I must point out, however, that it is not the carbon monoxide, *per se*, which causes this increased sulphide penetration, but the lower desulphurizing effect of a less strongly decarburizing gas.

In reply to Mr. Irvine, I would say that a typical peeled structure has been described and defined in the paper, but having examined several hundred peeled castings I would say also that there are several hundred types of peeled structure. The depth of the sulphide layer may vary ; it is not always continuous. The amount of oxide phase varies, and this is not always in the same form or distributed in the same manner ; and peeling often occurs even though the concentrated layer of sulphide is not always continuous.

The **Chairman** : In closing the meeting, I should like to thank the authors of the papers, the contributors to the discussion, and The Iron and Steel Institute.

I would emphasize again that the work done during the War was hurried, in the sense that it was necessary to find a solution without waiting for the mechanism to be fully explained. I am quite sure that everybody realizes that the best method of finding a perfect solution is to have a full understanding of that mechanism, and that was one of the reasons for promoting this discussion.

The meeting then terminated.

CORRESPONDENCE

Mr. **J. R. Binley** (Follsain Metals, Ltd.) wrote : With regard to the general conclusion that the higher the ratio of manganese to sulphur, within the metal, the lower is the tendency to peel, I should like to draw attention to the effect that is likely to be produced in the final metallographic structure of the annealed product.

I suggest the addition of a proportion of manganese

ore to the hematite ore as a possible means of " stabilizing " unavoidable sulphur accumulation within the ore, and so preventing diffusion of sulphur into the metal.

Mr. **A. A. Timmins** (Messrs. N. Hingley and Sons, Ltd.) wrote : The results of the work carried out during the war on behalf of the Iron and Steel Control, Ministry of Supply, amply confirm the data obtained by the authors of the papers under discussion. It was significant from the outset that the outbreak of peeling should have coincided with the issue of Riff ore, which not only had a higher sulphur content than the ores normally used by the industry, but, as pointed out by Webster and Probst, some of this sulphur was in the form of iron pyrites. A further point of significance was that, although there was considerable variation in the sulphur content of the spent ores used by various firms, it was noticeably higher where extensive peeling occurred. The influence of sulphur on peeling was confirmed by mixing sulphur or pyrites with the annealing ore, when peeling invariably resulted. Small pieces of iron sulphide placed on parts of the castings during packing produced peel in those places and nowhere else. The experiments showed that peeling was attributable to the ore and not to the castings themselves.

At the plant with which I was associated at the time it was believed that the free sulphur content of the ore was the main factor in peel formation, and attempts were made to remove it by spraying spent ore with dilute hydrochloric acid and also by a weathering process consisting of spraying with a dilute solution of sal ammoniac ; in both cases the ore was dried before use. Neither of these treatments was successful in removing the sulphur, which was presumably oxidized to sulphate, but a significant change occurred in the ore itself, which reduced its tendency to produce peeling. Weathering was particularly effective in this respect and the high content of ferrous and ferric oxides in the weathered ore was believed to be a factor. Tests with ore mixtures containing varying proportions of new and spent ores tended to support this view.

Experiment showed that peeling was not caused by diffusion of sulphur to the casting by direct contact of ore and metal, but that it was the result of a gaseous reaction which took place where there was an ore deficiency, *i.e.*, where conditions were likely to be reducing rather than oxidizing. This view agreed with the results of earlier experiments which showed that peeling was prevalent with weakly oxidizing ores or those tending to give reducing conditions. A theory was developed that peeling was due to the formation of a loose complex between carbon monoxide and sulphur dioxide which could exist only in an atmosphere with a low carbon dioxide content and that this complex permeated the ferrite layer towards the end of the anneal. Under oxidizing conditions of higher carbon dioxide content, obtained by a richer ore mixture, the complex was assumed to be unstable, splitting up into carbon dioxide and sulphur dioxide, the latter being incapable of permeating the ferrite layer.

This theory is in line with that developed by Norbury and Bowden which has been carried further by Bowden in his present paper. Coupled with the results of Preece's very careful experiments there is little doubt in my mind that peeling does occur in reducing conditions *via* the medium of a gas of the type COS. As a result of my own experience I should like to substantiate Bowden's recommendations for avoiding peel, but also to extend them somewhat. There is little doubt that a top limit should be placed on the sulphur content of annealing ore for three reasons : (i) The possibility of high-sulphur pockets, the effects of which cannot be nullified by increasing the proportion of new ore ; (ii) the possibility, in Riff ores, of pockets of free iron pyrites ; and (iii) a high sulphur content may necessitate a very strong ore mixture which may be untenable on other grounds, *e.g.*, in the annealing of small, thin-section castings which would scale in rich mixtures.

The sulphur content of the ore can be kept at a reasonably low figure by the following means :

(1) Use of new ore of low sulphur content.

(2) Control of metal composition to ensure that the manganese content is equal to, or higher than, the sulphur content, thus minimizing sulphur migration from casting to ore.

(3) Avoidance, as far as possible, of contact between annealing ore and furnace gases, by denser packing, careful luting, and elimination of pendulum annealing cycles.

(4) Screening of spent ore, aiming at the rejection of all fines below $\frac{1}{8}$ in. after each anneal. Experience has repeatedly shown that the sulphur content of spent ore tends to increase with decreasing particle size and particles below $\frac{1}{8}$ in. often have a high content.

It has been shown that peeling can be minimized by using stronger ore mixtures. However, when determining the ore strengths to be used, account must be taken of the following three factors, bearing in mind that too rich a mixture may lead to burnt castings : (i) The oxide content of the new and old ore ; (ii) the ratio of the weight of ore to the weight and surface area of the castings to be annealed (a low ratio will tend to reduce the oxidizing power of the ore more rapidly) ; and (iii) the ratio of new ore to spent ore in the mixture. It should be noted that spent ore has a lower apparent density than new ore ; to overcome this difficulty in making up mixtures by volume, Brynmor Jones recommends a determination of the bulk density by weighing the ore in a container of given size.

Perhaps the most noteworthy feature of peeling is its indiscriminate nature, *i.e.*, it is not always confined to any particular section or portion of a casting. Furthermore the pronounced peeling in the pin holes of track link castings, *i.e.*, in a position difficult to cover by ore, is noteworthy.

Peeling is clearly more pronounced when using ores of weak oxidizing power, but in my opinion most cases of peeling are brought about by a combination of weak ore and the formation of isolated reducing conditions due to bad packing.

The mixing of the new and old ore is usually carried out by hand, and even though on analysis the oxide content of the mixture may be reasonably high, it is possible, owing to bad mixing, particularly with high percentages of old ore, for pockets of spent ore of weak oxidizing power to occur within the packed can. Certain firms adopt the practice of filling the pots with castings, the ore being shovelled in afterwards. Such a practice is open to criticism in that there is a strong possibility of voids or pockets being left in the ore. In both cases localized reducing conditions will obtain and peeling is likely to occur.

Weathered ore is regarded as being more efficient in preventing peeling than richer ore mixtures. Each piece of spent ore assumes its quota of ferric oxide, and the tendency to give isolated pockets of ore low in this oxide is avoided.

I would support Bowden's remarks concerning the composition of the metal in relation to peeling, as experience shows that high-silicon irons (above 0·6%) show a greater tendency to peel. Likewise, a high-manganese iron tends to offset the defect.

I consider, however, that these points are minor ones

compared with the control of ore mixture. The following factors of works practice are the most important if peeling is to be avoided :

(1) A new-ore/old-ore ratio of adequate strength should be used.

(2) The proportion of mixed ore should be adequate for the weight of castings being annealed.

(3) The ore should be mixed properly before packing and the castings embedded firmly in the ore ; there should be no bridging or voids.

(4) All old ore should be screened to reject particles below $\frac{1}{8}$ in.

(5) The spent ore should be weathered, particularly if light castings are being annealed, and in cases where a high percentage of new ore may give burning.

AUTHORS' WRITTEN REPLIES

Mr. **A. Preece** and Mr. **K. J. Irvine** wrote in further reply : We think that before dealing with individual questions many points would be clarified by consideration of the following :

(1) The presence of metallic iron in spent ore is clear evidence that in certain regions inside the annealing box the atmosphere can attain a high carbon monoxide content. It also emphasizes the fact that analyses of gases withdrawn from the box can be only an average value and may be misleading.

(2) Any explanation of peel formation must have regard to the experimental fact that it is the CO/CO_2 ratio which determines whether sulphur will be absorbed by or removed from the iron during the malleablizing operation.

(3) In a large number of experiments no evidence whatsoever was found that a segregation of sulphide into a band, as seen in peeled casting, occurred unless the CO/CO_2 ratio in the external atmosphere was changed. Fundamental considerations also confirm this finding.

(4) Sulphide penetration in the form of a molten iron sulphide complex does not require the presence of an oxide or silicate phase.

Mr. Peace describes our paper as an academic approach with but little attempt to simulate works conditions. This we feel is an inaccurate description, as throughout the experiments every attempt was made to reproduce conditions likely to be encountered in the annealing box, in such a way that they would be under close control. As Mr. Peace indicates, the main difference of opinion in the papers concerns the particular atmosphere which is conducive to peel formation, and this point is considered later.

Mr. Jenkins offers an alternative theory to explain the constant depth of penetration over the temperature range 1000–1200° C, and suggests that the controlling factor is the carbon potential on the inner face of the sulphide band. The authors believe, however, that this is an over-simplification of the mechanism involved, since carburization at the gas–metal interface must be considered. In this connection, experiments with hydrocarbon gases have not been tried, but should prove interesting. The magnification shown in Figs. 4 and 6 should have been given as × 15, which would agree with Mr. Jenkins' calculation.

Reference was made to the depth of intercrystalline oxidation in the three irons treated in the sulphur-free $CO–CO_2$ gas mixtures. Our Fig. 5 shows that this depth is very much less than the depth of decarburization, which evidently exerts little effect. For this reason the previously malleablized iron would be expected to behave similarly to the two as-cast irons.

In answer to the statement that our work was based on an assumption that the atmosphere changes during the course of the annealing cycle, we would say that the weight of evidence confirms our point of view, as do Mr. Morrogh's remarks made during the discussion. There is also the significant remark of Dr. Schulte : " . . . locally quite different conditions may exist in the annealing pot . . . near the castings it will always tend towards a higher carbon monoxide concentration." In view of this evidence we feel that it would be a quite unwarranted assumption to say that the gas composition in contact with the iron would remain constant. The very fact that metallic iron is found in spent ore is again a confirmation that in certain places in the annealing box the atmosphere must be high in carbon monoxide.

Together with other speakers, Mr. Jenkins shows that there is no disagreement between our limit of 10% of CO_2 for sulphide penetration with 0·3% of SO_2, and the fact that Bernstein obtained penetration with 20% of CO_2 with 1% of SO_2 present. This is undoubtedly true. We have used a range of sulphur contents, though never reaching as high as 1% of SO_2 and, as pointed out in the paper, 0·1% of SO_2 was finally chosen since it produced structures most closely approximating to those found when examining industrial peeled specimens. With this sulphur content 25% of CO_2 is desulphurizing.

With reference to the presence of oxide in the scale produced in an atmosphere of 80% CO/20% CO_2/0·3% SO_2, the authors would point out that this system contains iron sulphide, and the experimental results show clearly that iron oxide is stable in this system. A silicon content is not essential, as was shown by similar experiments with Armco iron having a very low silicon content.

With regard to the explanation put forward by Mr. Jenkins, he would seem to reject the idea of sulphur pick-up from the atmosphere, and to attribute peeling to a migration of sulphur in the surface layers of the metal. There is, however, very definite evidence that a sulphur pick-up—which is sometimes very large—does occur in industrial malleablizing, and we have proved conclusively that a sulphur pick-up does occur with certain CO/CO_2 ratios.

Mr. Hancock raises the question of the effect of carbon on the movement of sulphur. In all our work we have found no evidence that sulphur can move against a carbon-concentration gradient but much evidence that the converse is true. The experiments with carbon steels still required a carbon-concentration gradient before penetration occurred. It has been suggested that in attempting the experimental work the maximum elimination of variables should have been attempted. This in fact was done and the effect of variables in iron composition and annealing atmosphere was treated separately. In this way the confusing effects of decarburization and graphitization were eliminated.

Mr. Hancock has pointed to the carburized surface of the peeled specimens produced in $CO–CO_2$ atmospheres in the laboratory as an essential difference between these examples of peel and those found normally in industry, where the surface of the casting contains little carbon. It should be pointed out that such a structure as shown in our Fig. 11 does not imply appreciable carburization, and under the conditions of slow cooling would closely resemble those produced industrially.

The use of sulphur dioxide instead of hydrogen sulphide is justified by the fact that as the gases approach the hot zone of the furnace decomposition of each gas occurs, producing elemental sulphur and a mixture of H_2S and SO_2.

Mr. Morrogh rightly stresses the importance of the sulphur content of the ore as being the main factor in peeling, and also that a satisfactory procedure to eliminate peeling for high-sulphur-containing ores cannot

be recommended. Although we show that with above 20% of CO_2 sulphide penetration will not occur, the intercrystalline oxidation will still be ten times as great as with a sulphur-free gas mixture. This increased depth of oxidation will depend upon the sulphur content, and therefore the maximum sulphur content of the ore that can be used will depend upon the depth of inter-crystalline oxidation that can be tolerated. There is no statement in our paper that the formation of an oxide or silicate phase is a necessary preliminary to sulphide penetration. The opposite is definitely stated in the first paper, and sulphur penetration in the absence of silicon or oxygen is clearly shown in the second. However, since the cast iron always contains appreciable silicon, and as malleablization is always carried out in a CO–CO_2 atmosphere, peeling is invariably associated with an oxide network. We are able to endorse his remarks about the effect of silicon and have found that the silicon/manganese ratio is of greater importance than the manganese/sulphur ratio in governing the formation of manganese sulphide. In a particular iron with 1·7% of silicon and 0·14% of manganese a eutectic was formed under reducing conditions, containing silicon, possibly in the form of a silicon sulphide.

The contribution of Dr. Schulte is extremely interesting, but the curves shown must be accepted with his reservations (1) that local conditions round the castings may be completely different, and (2) that sulphur will completely change his conjecture of conditions inside the metal. Ample proof of the wide differences occurring in local regions in an annealing pot is given by differences in the degree of peel formation often in the same casting. It is difficult to visualize the macro-diffusion of manganese and silicon suggested by Dr. Schulte in view of their slow rates of diffusion in iron.

Mr. Dovey raises the question of the possibility of sulphur diffusing in front of the sulphide band ; generally, the rate of advance of the sulphide band far exceeds the rate of diffusion of sulphur, thus no sulphide would be expected in front of the band. When the movement of the sulphide is prevented by a high carbon concentration, the diffusion of sulphur away from the large sulphide particles takes place, but much more slowly, and appears as the concentration of very small manganese sulphide particles shown in our Fig. 12 of the paper on sulphide penetration. High contents of manganese and silicon appeared to minimize this. There is no evidence to show that diffusion of oxygen could cause movement of a sulphide band ; in fact it has been shown that sulphur can diffuse against a concentration of oxygen when specimens were desulphurized. When referring to the effect of silicon, attention must be paid to the experiments which were being carried out. Silicon was shown to reduce the rate of penetration of sulphide in an iron containing no carbon. Silicon increases peeling in a cast iron mainly because decarburization is more rapid with a high-silicon iron. There is no contradiction between these two results. Mr. Dovey indicates that when carburization has continued for some time, the diffusion of manganese and silicon will be comparable to that of carbon, which leads him to many wrong conclusions concerning reactions likely to occur within the iron. Mr. Dovey asks whether the oxide band produced by the removal of deep-seated sulphide would itself disappear on continued exposure to a gas mixture of 80% of CO and 20% of CO_2. An experiment to establish this possibility would be prolonged, but from theoretical considerations it should be possible to reduce this oxide to iron.

With regard to COS the authors failed to find any evidence of its existence in the present experiments, and Miss J. Bayley, in a comprehensive examination of the effect of sulphur on the equilibrium in FeO, CO, CO_2 systems, in the authors' laboratory, also failed to produce COS in measurable quantities even in experiments designed solely for this purpose.

Mr. Bernstein mentions that the gases used in our experiments contained a small quantity of moisture. Whilst agreeing that in certain work the use of phosphorus pentoxide may be desirable as a drying agent, in this particular case the use of calcium chloride was deliberate. It is known that the first small quantity of moisture exerts an important effect. Perfectly dry gas mixtures could not reproduce conditions likely to be encountered in the annealing box, but there has been no published information on the amount of moisture likely to be present in the annealing atmosphere. Calcium chloride provides a convenient means of overcoming this objection without introducing a further variable of composition.

Mr. **J. S. Bowden** wrote in reply : As undue stress seems to have been placed on the sulphur content of the ore, I must point out that peeling troubles were encountered many years ago when the industry used only low-sulphur Cumberland hematite. There seems to be little point in specifying a maximum sulphur content for annealing ores until the safe upper limit is definitely known. Much of the sulphur in Riff ore is present as fairly large particles of pyrites, and accurate sampling would not be easy.

The silicates, which are usually found in the oxidized metal and at the peel–metal interface, seem to have been overshadowed by discussions of the sulphide band.

In reply to Mr. Jenkins, I did not intend to suggest that complex molecules diffuse into the iron, but that complex reactions take place as carbon, oxygen, silicon, and sulphur migrate within the casting. Dr. Schulte's confirmation of the view that silicon will be preferentially oxidized and that silica will attract FeO and MnO to form complex silicates, is reassuring. His contribution has demonstrated the complexity of the reactions which take place during malleablizing and has added to the value of the discussion.

The correspondence from Mr. Timmins is particularly welcome as he was in close contact with the malleable-iron industry throughout the War. The fact that peeling occurs indiscriminately and that peel may be localized, as shown by the illustrations on pages 9 and 10 (Symposium), confirms Dr. Schulte's opinion that different gas compositions may exist in different parts of the annealing pot. Careful screening to eliminate fines will undoubtedly reduce the sulphur content of spent ores. At the same time it will provide a coarser packing material in which there will be increased opportunity for rapid diffusion of gas between the particles.

Mr. Bernstein's assertion that peeling troubles are still being experienced hardly supports the view that Riff ores are the primary cause of peeling, for no Riff ore has been supplied to annealers since 1943. I am interested by his statement that certain firms are temporarily overcoming peeling by increasing the strength of their ore.

Mr. **J. Bernstein** wrote in further reply : Further to the comments of Mr. Peace, on the form of sulphur in annealing ore, I would add that peeling may also result when the sulphur is present as sulphate. I have produced peeling in samples annealed in a mixture of limestone and granite chippings to which sulphur was added as ferrous sulphate. I agree with Mr. Peace that the same reaction may not take place in every case of peel and I place more emphasis on the rôle of the iron/iron-sulphide eutectic than on the oxide eutectic.

The results of experimental work carried out since my paper was submitted for publication led me to the same conclusions as those given, in the form of an equation involving partial pressures, by Mr. Jenkins, and I would advance an explanation for the results I have obtained with rich and weak ores similar to that offered by him. It is known that from 40 to 75% of the available sulphur in annealing ore may be evolved in about 3–4 hr at 900° C. The particular atmosphere in which the ore is heated governs the actual figure obtained. I believe Preece and Irvine have experimental evidence which would confirm this. In view of this it would seem logical to assume that in normal whiteheart malleable practice the amount of sulphur liberated from sulphur-containing ore decreases during the progress of the anneal. Further, it is perhaps reasonable to assume that the sulphurous gases contained in the products of combustion of the heating fuel remain at a fairly constant value during the progress of the anneal, except during cooling when combustion of fuel is halted. The total sulphur content of the atmosphere surrounding the castings is thus lower during the later stages of the anneal, and I consider it possible that it may be sufficiently low to effect some measure of desulphurization, producing curves for sulphur distribution in the metal, of the type shown in my paper. Desulphurization may occur at temperatures considerably lower than the top annealing temperature. The character of the sulphur-distribution curve shown in Fig. 29 was obtained in all experiments where the sulphur content of the annealing atmosphere was maintained throughout the anneal and during cooling.

The sulphide band in commercial peeled castings is not always continuous and rarely is as concentrated and pronounced as shown in the laboratory sample illustrated in Fig. 13 of the paper by Preece and Irvine. It is my experience that it is more frequently observed as illustrated in Figs. 11 and 12 (Preece and Irvine), Fig. 7 (Bowden), Figs. 12 and 13 (Webster and Probst), and Figs. 2, 4, 6, and 13 (Bernstein). In these illustrations it will be observed that the sulphide is concentrated at the crystal boundaries and it is, I feel, quite in order to assume that the carbon may be removed from the iron by diffusion through the austenite crystals in preference to, or at least as easily as, diffusion through the sulphide collected at the crystal boundaries. I think that the metallographic evidence in my paper amply justifies this. Cases of very heavy peel do show a more or less continuous band of sulphide, but they are the exception rather than the rule. I hesitate, therefore, to accept unreservedly the idea that the movement of the sulphide band proceeds entirely by a process of solution and precipitation, or that it moves forward primarily under the influence of carbon monoxide.

Mr. Hancock's assertion that the use of sulphur dioxide was illogical should not be allowed to pass unchallenged. On numerous occasions I have detected sulphur dioxide in the atmosphere of gas-fired and solid-fuel-fired malleablizing ovens. I used hydrogen sulphide in a number of experiments and, except in the case of the dry hydrogen experiments sulphur dioxide was more in evidence in the waste gases than hydrogen sulphide. Further, the former gas appeared generally to be the more suitable and the more satisfactory of the two under the conditions of this investigation. With regard to the rate of flow of the gas, experiments were carried out to determine the optimum rate, and considerable care was taken to ensure that no errors in the reported results could be ascribed to an insufficient rate of gas flow.

The contribution of Dr. Schulte, whilst approaching the problem from a slightly different point of view, tends to support my findings, and I entirely agree with him that as long as desulphurizing conditions exist, peeling will not occur.

In reply to Mr. Nicol Smith, the Fe_2O_3 figure quoted on page 21 of my paper is lower than would be expected by calculation from the Fe_2O_3 content of the new and used ore, and from the new-ore/used-ore ratio. A rough calculation gives a figure of 10%. A number of determinations of the "available" oxygen in ores after annealing were carried out, but no significant information was obtained.

I am pleased that Preece and Irvine were able to confirm my results in their experiments on similar material supplied to them. That we do not derive the same conclusions from these results in no way lessens their value and is, in fact, understandable, as we then proceeded to work along somewhat different lines. I assure Mr. Irvine that the greatest care was taken to ensure that my experimental conditions did not vary and that in my opinion the results on page 29 of my paper are not conflicting.

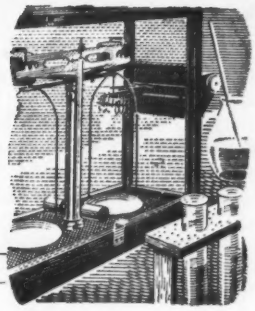
In reply to Mr. Irvine's query on the effect of manganese, the last sentence in conclusion (2) on page 32 of my paper does not imply that manganese will effect a certain prevention of peeling in all cases, and this statement does not appear to me to contradict my further statement on page 36. The higher sulphur dioxide percentages used in my experiments probably account for the different results obtained by Preece and Irvine in sulphur-containing atmospheres containing less than 10% of carbon dioxide.

The weight of evidence in my own and other papers supports my conclusion that excessive sulphur in the annealing ore or in the annealing atmosphere is the primary cause of peeling. The factor of weak ore stressed by Mr. Bowden has less significance and it is important that the malleable-iron founder should realize that peeling will not occur when the sulphur contents of the ore and the annealing atmosphere are low. The functions of ammonium chloride in malleablizing are, as far as I am aware, restricted to a process of regeneration of spent ore. At one time it was, I believe, hoped to remove some of the sulphur in spent ore during the regeneration process by spraying the ore with a dilute aqueous solution of ammonium chloride, followed by prolonged atmospheric exposure. Dilute acid was also used in this connection. I doubt whether the addition of manganese ore to hematite ore would prevent the diffusion of sulphur into the metal, as suggested by Mr. Binley, but it may be worth trying on an experimental scale.

The average malleable-iron founder is not concerned with the exact mechanism of sulphide penetration; he merely wants to produce castings free from peeling. I believe that sufficient information is now available to enable the producers of whiteheart malleable iron to overcome peeling if they meet this phenomenon in the course of normal production. The apparent disagreement between the findings of some of the authors is confined to relatively minor points which will, no doubt, be resolved in the future. That the primary cause of peeling is excessive sulphur in the annealing ore or in the annealing atmosphere cannot be too strongly nor too often emphasized.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



The Interpretation of Fouling Samples from Ships

By M. W. H. Bishop, B.A., K. A. Pyefinch, M.A., and Molly F. Spooner, Ph.D.

SYNOPSIS

The kind of results that can be obtained, and deductions that can be drawn, from a set of samples of the fouling from a ship, are described. Acorn barnacles, tube-worms, and oysters are the major animal fouling organisms, the green seaweed *Enteromorpha* and the branched brown seaweed *Ectocarpus* are the major plant forms.

Examination of the samples, together with counts and measurements of some of these major fouling organisms, give some idea of the sequence of fouling settlement. Correlation of this sequence with the route makes the reconstruction of a fouling history possible, an example of which is given. The reconstruction of a fouling history enables an estimate of the length of 'life' of the anti-fouling paint to be made. The deliberate provision of non-toxic areas would help considerably in forming this estimate.

Many reconstructions of fouling histories are tentative and a higher level of certainty will be reached only when fuller biological information is available. However, it may be concluded that the average service period is considerably greater than the average length of life of the anti-fouling compositions used. It is emphasized that the absence of fouling on dry-docking is not valid evidence of the effectiveness of the anti-fouling composition throughout the voyage.

Introduction

THE programme of research on the fouling problem, carried out by the investigators of the Marine Corrosion Sub-Committee,* has always included work on the examination and identification of samples of fouling from ships. These samples have been obtained from several sources. Many were submitted by shipowners, graving-dock owners, and by private individuals, or were obtained by investigators during visits to ports (particularly Liverpool), and some were collected when inspecting tests of experimental anti-fouling compositions developed by the Sub-Committee's investigators.[1] Approximately 500 sets of samples have been collected.

Later publications will discuss the results more fully. The aim of this paper is briefly to describe the kind of results obtainable under favourable circumstances, and to indicate the importance of a critical analysis of the performance of the anti-fouling composition after a period of service. The shipowner may feel that it is not difficult to rate a ship as 'fouled' or 'unfouled' on its return to dry-dock after a voyage, but a critical examination of the reasons why either state has been attained is well worth while. A ship may be unfouled after a period at sea, but this absence of settlement may be due to reasons other than the efficient action of the anti-fouling composition.

THE MAJOR FOULING ORGANISMS

A brief account of the more important fouling organisms, a subject dealt with more fully in an earlier publication of the Sub-Committee,[2] is given in the following paragraphs.

Acorn barnacles are the most important animal fouling organisms. In tropical and sub-tropical waters *Balanus amphitrite* and, to a less extent, *B. tintinnabulum* are the two species which settle most frequently on ships' bottoms, whereas in northern temperate waters *B. crenatus*, *B. improvisus*, and *B. balanoides* occur most often.

Calcareous tube-worms, particularly species of the genus *Hydroides*, rank next in importance to the acorn barnacles, and oysters also occur frequently, either on the paint, or attached to other organisms. Other animals, such as hydroids and encrusting Polyzoa, are also common, but are less important than acorn barnacles, tube-worms, and oysters, because they do not, in general, produce structures likely to impede materially the passage of a ship through the water.

* A Sub-Committee of the Corrosion Committee, which was initially a Joint Committee to The Iron and Steel Institute and the British Iron and Steel Federation, but which, since 1st January, 1946, has been a Committee of the British Iron and Steel Research Association.

Paper MG/BC/37/48 of the Marine Corrosion Sub-Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 1st July, 1948. The views expressed in the paper are the authors' and are not necessarily endorsed by the Sub-Committee as a body.

The authors were members of the Anti-Fouling Section at the Marine Station, Millport, Isle of Cumbrae, when the paper was written.

Plant fouling organisms are often present in abundance at, or near, the water-line. The bulk of this settlement is formed by the green seaweed *Enteromorpha*, but a small, branched, brown seaweed, *Ectocarpus*, is not uncommon, though its occurrence is often not apparent to the naked eye among the more conspicuous *Enteromorpha*.

This brief list could be extended considerably, since a number of other forms have been recorded as occurring on ships. Visscher[3] lists over 60 species of animals, and nearly 20 species of plants, but the majority of these are not common. These other organisms are infrequent and of little importance in assessing the performance of an anti-fouling composition. Many occur only if fouling has been heavy, so that the growth has developed into a complex community. The structure of the latter is of great biological interest, but the most important organisms are those which first settle and persist, not those which can survive only if other organisms are already present to give shelter or protection. Thus, although the organisms mentioned earlier represent, roughly, only one-tenth of the various species which have been recorded, they form perhaps 95% of fouling in general. Illustrations of these major fouling organisms will be found in the earlier publication already mentioned.[2]

METHOD OF EXAMINATION OF SAMPLES

The first step in the examination of a sample of fouling is to wash the organisms free from the mud and debris with which they are almost invariably mixed. If macroscopic fouling is obviously present, washing can be vigorous, since the analysis is clearly going to depend upon the macroscopic forms (acorn barnacles, tube-worms, green seaweed, etc.) present. If macroscopic fouling forms are apparently absent the sample is washed more cautiously, because paint chips and paint debris must be examined for recent settlements, which are usually minute, or for the presence of bacterial or diatom slimes. The presence of minute barnacles and tube-worms (less than 3 mm. long) may be important evidence that the anti-fouling composition has just ceased to give adequate protection, whereas the presence of slimes may indicate that the anti-fouling properties of the paint were still adequate on dry-docking, and therefore that the absence of macroscopic forms is a genuine result (*see* Pyefinch[4]). If such a sample were washed vigorously, much important evidence might be removed.

The organisms present are then roughly sorted into types (tube-worms, acorn barnacles, etc.), identified, and the specimens of each type counted and measured, if possible. Acorn barnacles and oysters can readily be counted and measured, but such operations are not easy for the other major fouling organisms. It is extremely difficult to remove tube-worms without breaking the delicate calcareous tube, so that it is usually possible only to obtain a rough idea of the quantity of these organisms in a sample. Measurements of the other animals and plants are either impossible to make with sufficient accuracy (*e.g.*, hydroids, encrusting Polyzoa, which have a spreading habit of growth and are often damaged), or have little meaning (*e.g.*, plant fouling organisms, which may grow and die down several times in the course of a voyage).

Counts reveal the relative number of each type present, and measurements show both the average size attained and, on occasion, whether more than one settlement of a species has occurred. From the total numbers present and estimates of quantity (in the case of those organisms which cannot easily be counted) some idea of the severity of fouling can be gained. It is rarely possible, however, to obtain more than a rough idea of density of settlement, as details of the extent of the area sampled were only occasionally provided. The entries in the completed dry-docking report form (*see* examples previously published[2]) are useful as a rough guide, but reliable comparisons can only be made between one set of fouling samples and another, or between fouling samples from different parts of the same ship, if the extent of the areas sampled is known. The lack of this information has been one of the outstanding deficiencies of those sets of samples submitted by ship and graving-dock owners during the course of the present survey. It should also be emphasized that valid deductions from the sample are possible only if the latter is representative of the state of the hull as a whole.

RESULTS OF EXAMINATIONS OF FOULING SAMPLES

Sequence of Settlement

Figures 1 and 2 show, diagrammatically, the settlements which had occurred on two ships. Though these figures have been based on samples analysed, the reconstructions of the appearance are somewhat tentative, as the areas from which the samples were removed are not known in either case, but they are believed to be reasonably accurate.

Figure 1 represents barnacles only. Settlement had evidently been heavy, but none had grown to a very large size ; measurement of their diameters gave the following results :

Base Dia., mm.	No. of Barnacles	Base Dia., mm.	No. of Barnacles
0–1	0	5–6	86
1–2	5	6–7	45
2–3	37	7–8	12
3–4	79	8–10	2
4–5	136	10–12	0

The largest size group is that of basal dia. 4–5 mm. Further, if these figures were plotted the resulting curve would be approximately symmetrical about the maximum, *i.e.*, the number of barnacles with bases 4–5 mm. in dia. This strongly suggests that the sample represents one settlement. These barnacles probably did not all settle exactly at the same time, but, as the species concerned, *Balanus amphitrite*, is a tropical form known to grow rapidly immediately after settlement, it is possible that all settled during a week or ten-day's call in one port, and this is recorded as one settlement.

Figure 2 shows *Balanus amphitrite* and calcareous tube-worms (*Hydroides* sp.). Some of the barnacles had settled on the paint surface but others on the shells of the earlier settlement of barnacles. The existence of such epizoic specimens can usually be

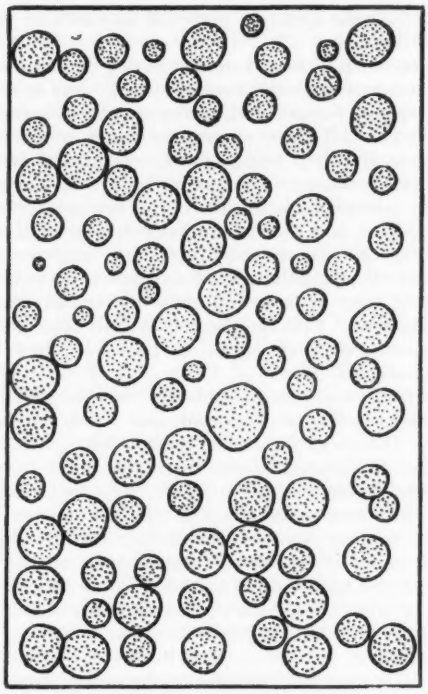


Fig. 1—Diagrammatic representation of the appearance of a single barnacle settlement on a ship's hull. The barnacles are drawn roughly at natural size

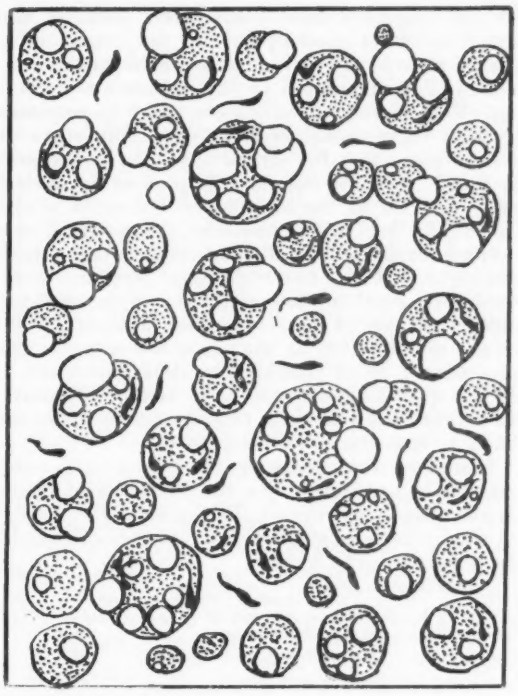


Fig. 2—Diagrammatic representation of several fouling settlements on a ship's hull. The basic barnacles are shown dotted; the epizoic barnacles, undotted; tube-worms, black. Roughly natural size

considered to be clear evidence of two distinct settlements. Basal diameter measurements were as follows :

Base Dia., mm.	Number of Barnacles	
	Epizoic	Basic
0–1	33	0
1–2	102	1
2–3	188	4
3–4	175	14
4–5	80	29
5–6	27	28
6–7	18	20
7–8	6	36
8–10	2	60
10–12	0	52
12–14	0	28
14–16	0	13
16–18	0	5
18–20	0	1

Among the epizoic specimens the largest size group is that of basal diameter 2–3 mm. and it would seem likely that all these barnacles settled at one time, *i.e.*, during a visit to one port. The situation is not so clear, however, for the basic specimens, since when these figures are plotted, the curve obtained rises to a maximum in the 4–5 mm. group, then falls and again rises to a maximum in the 8–10 mm. group. This may mean that two settlements of barnacles had colonized the paint surface.

Further, the tube-worms occur either on the paint or on the larger barnacles ; in no case does a barnacle with a base less than 6–7 mm. in dia. bear a tube-worm. This suggests that the tube-worm settlement occurred *after* the first group of barnacles had settled on the paint, but *before* the second group of *basic* barnacles had settled. Thus, for this sample of fouling, the sequence of settlement may be given as :

1. Barnacles (*Balanus amphitrite*)
2. Tube-worms (*Hydroides* sp.)
3. Barnacles (*B. amphitrite*)

By observations of this nature it is often possible to obtain a rough idea of the fouling sequence. Such sequences, however, should be cautiously interpreted since, though they are records of the sequence that has occurred, they are not necessarily records of all the settling stages of fouling organisms which have been encountered. This is because the settlement of one form may make that of another form virtually impossible. Thus, if a heavy settlement of tube-worm has occurred, the irregular surface produced is not suitable for barnacle settlement. If a ship first spends some time in the Mediterranean (when tube-worm fouling can be heavy), and then visits West African ports (where barnacles are common), the settlement of fouling in the Mediterranean can minimize, or eliminate, settlements which might have been possible later. This factor of biological exclusion may seem academic, but it has to be considered when attempting to reconstruct a fouling history. From the practical standpoint it is the stage of the voyage at which colonization first occurs which is important.

Fouling Histories

The next step is to attempt to correlate the sequence of settlements with the sequence of ports visited. However, other factors which may affect fouling settlement and survival must first be mentioned.

So far, emphasis has chiefly been laid on the accumulation of fouling, but in the course of a voyage a ship may call at ports where the environment is not favourable to the persistence of fouling. Most marine organisms are killed by exposure to fresh water, and, therefore, if a ship stays at a fresh-water port for several days, any fouling will be killed. Some of this may drop off or be washed away as soon as the ship moves, but much of the 'shell' fouling (acorn barnacles, tube-worms, and oysters) remains, though the soft contents of the shells disappear. A visit to a fresh-water port may therefore show itself in the occurrence of a considerable proportion of dead barnacles, or other 'shell,' in the sample taken at the end of the voyage. The presence of small numbers of dead individuals is of no special significance as it is not necessarily an indication of a period in fresh water since some are likely to have died for other reasons.

Sometimes the effects of a visit to a fresh-water port can help considerably in the correlation of fouling sequence and ports visited. For example, the analysis of the barnacle population from one set of samples gave the following results :

Settlement Sequence	Species	Dead, %
1	*Balanus amphitrite* var. i.	100
2	*B. amphitrite* var. ii.	0
3	*B. amphitrite* var. ii.	0

These results indicate that a visit had been made to a fresh-water port between the first and second settlements, which would cause the death but not the disappearance of shell fouling.

A visit to a scouring port (*e.g.*, the Congo port of Matadi, Shanghai, Calcutta—if at anchor in the River Hooglie, etc.) may result in the disappearance of both soft-bodied and shell fouling. A ship may enter such a port fouled, and leave completely clean, and if she then returns to her home port without any further long calls, she may arrive clean. This result is thus not a reliable estimate of the anti-fouling properties of the bottom composition used.

The following example shows how a fouling history is reconstructed. Such histories are frequently tentative ; sometimes more than one explanation will reasonably fit the facts, but the one given is that which appears most likely to be true.

The history of the service period is presented in Fig. 3. The period out of dry-dock lasted between 13 and 14 months, and the ship made one transatlantic voyage and three to West Africa. Altogether 250 days were spent in port, out of a service period of 413 days.

When the hull was examined in dry-dock a number of large acorn barnacles were observed, some belonging to the species *Balanus tintinnabulum*, others to *Balanus amphitrite*. All these showed evidence of extensive abrasion, the shell being pitted, eroded and even, in some cases, worn away, leaving only ring-like traces of the calcareous basal plate. A few oysters were also present and showed similar evidence of abrasion (*see* Fig. 4). There was also some evidence of a settlement of medium-sized barnacles, though most of these were represented only by traces of their basal plates. Finally, the whole hull bore a heavy settlement of very small barnacles. These were practically all dead.

Barnacle settlement probably first began during the visits to Lagos, Takoradi, and Freetown, late in May. These barnacles had reasonably good opportunities for growth since, after the ports in which settlement took place, a number of long, or moderately long calls were made (*see* Fig. 3). The medium-sized barnacles may have settled either during the first three weeks of September, during calls at Takoradi, etc., at the beginning of the next West African coast trip, or later, during the visits to Lagos and Freetown, in October. The important characteristic of this second West African voyage, however, is the calls at Port Harcourt and Calabar. These are fresh-water ports and the periods spent in them are long enough to kill the acorn barnacles and oysters which had settled earlier.

The third voyage to the West African coast included a call of 20 days at Matadi, and this visit was responsible for the removal of practically all the fouling then present. The efficacy of the scouring action at this port may well have been increased by the fact that much of the fouling was already dead when the ship arrived there, but there is no doubt about the drastic effect of the three-week stay in this port.

Settlement of the minute barnacles took place after the Matadi visit, perhaps at Lagos. The death of these very small barnacles was due, not to exposure to fresh water, but to the sea passages which followed their settlement. The lethal effect of a lengthy sea passage on small barnacles has frequently been noted in the course of this work, and these deductions have been confirmed by direct experiment (Walton Smith[5]).

This reconstruction suggests that the anti-fouling paint applied at the end of January was not able to

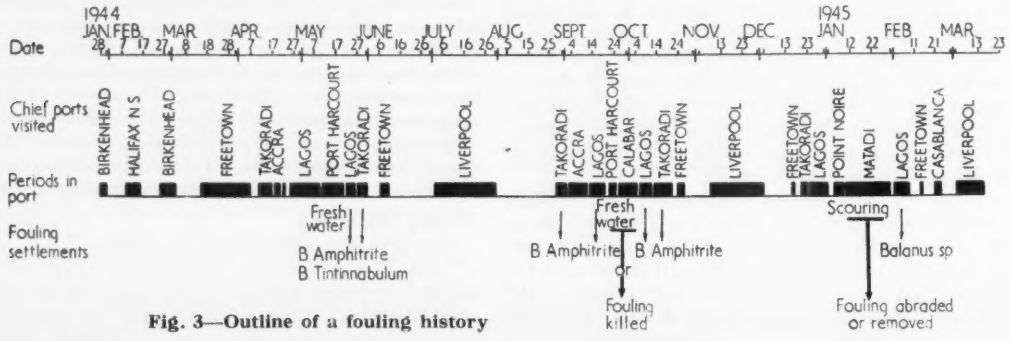


Fig. 3—Outline of a fouling history

prevent settlement towards the end of May. Its period of effectiveness, therefore, did not exceed four months. It is possible that this period was even shorter, as it will be noted (*see* Fig. 3) that a ten-day call at the fresh-water port of Port Harcourt was made in mid-May. Some settlement might therefore have occurred before this call, but the fouling organisms concerned, if any, after having been killed at Port Harcourt, would have decayed and been washed away before the voyage ended.

The reconstruction of a fouling history thus enables the biologist to suggest the time during the voyage at which the anti-fouling composition used was no longer effective. The accuracy of this determination would be appreciably increased if there was some part of the hull upon which fouling organisms could settle at any stage of the voyage, *i.e.*, if an area were not coated with anti-fouling paint. When testing experimental anti-fouling compositions on rafts, non-toxic areas are always included among those coated with the toxic compositions. The amount and kind of settlement on the two types of surface can then be directly compared. If both remain unfouled, it is clear that the unfouled condition of the toxic surface is probably due to lack of fouling organisms; if the non-toxic surface becomes fouled and the toxic surface is unfouled, the latter must be exerting some anti-fouling action.

Some shipowners coat an area near the stern with an 'anti-galvo' composition. This composition usually has excellent protective properties, but lacks anti-fouling properties, and it can therefore serve as a non-toxic control area. There are, however, reasons for supposing that settlement on such an area is not altogether typical, so that it would be better if the non-toxic area could be situated elsewhere. It need not be large; if a single plate were left uncoated with anti-fouling paint, it would serve admirably. The site chosen should be readily accessible from the dry-dock bottom, and should bear the same relationship to some point of reference, *e.g.*, at the after-end of the bilge keel, on each ship. All concerned with the painting, cleaning, and inspection of the hull should then be in no doubt as to its situation. A comparison of the kind of fouling on this area with that on neighbouring areas would enable the port at which settlement first occurred to be deduced with greater certainty. Even if a detailed biological analysis were not possible, much might be learned from a general comparison. Such a comparison would not show any differences, if, by the time the first fouling settlements were encountered, the anti-fouling composition was no longer effective. Such a condition has been noted on ships sailing direct from this country to the Far East. A shipowner who found that such a condition regularly occurred would be in no doubt as to the ineffectiveness of the anti-fouling composition; indeed, he might conclude that the amount of fouling which normally occurred would not be altered if he omitted the anti-fouling coat.

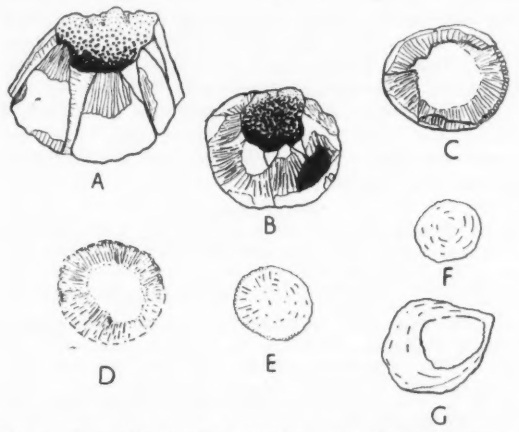


Fig. 4—The effects of a scouring port; fouling from a ship which had stayed three weeks in the Congo port of Matadi. A, a specimen of *Balanus tintinnabulum*; B–F, specimens of *Balanus amphitrite*; G, the worn lower valve of an oyster. Reproductions are natural size

DISCUSSION

If a reliable fouling history could be reconstructed for every voyage, it would give a clear idea of the points at which fouling would be most likely to occur. The example given in the preceding section has been selected as a good instance of the correlation between fouling sequence and route. In many cases, however, such reconstructions can be made only tentatively and much more information is often needed for this correlation to be made with reasonable accuracy.

Much of this missing information is biological in nature and not likely to be rapidly acquired, as it mainly consists of general observations made at many ports all over the world. The type and amount of settlement at various seasons, for instance, is only known for a few areas, mainly in temperate waters. More knowledge of the growth of the major fouling rates is also necessary. Many common fouling organisms are widely distributed geographically; the acorn barnacle *Balanus amphitrite*, for example, occurs all over a wide belt of tropical and sub-tropical waters extending from the Mediterranean to Australia and New Zealand. Within this range it must encounter, and survive, a wide range of environmental conditions and its rate of growth is doubtless very different in different parts of its wide area of distribution. A striking example of difference in growth rate at different places is provided by the tube-worm *Hydroides norvegica* which is more widely distributed even than *Balanus amphitrite*. Bishop (results unpublished) found that its tube could grow to 40 mm. in three months in the summer in the Firth of Clyde; Paul[6] records that this length is attained in three weeks in Madras Harbour. Since many of the deductions made in the reconstruction of a fouling history depend upon the length of time that a fouling organism has taken to reach a particular size, variations of the order just quoted mean that these deductions can be drawn only tentatively until more biological information is available.

Although this lack of biological information hampers the reconstruction of detailed fouling histories, the general deductions from these studies can be considered to be reasonably accurate. One

of the most important of these is that most of the anti-fouling compositions used in Great Britain do not provide effective protection against fouling, under either tropical or temperate service conditions, for more than four months. In the history described previously the length of anti-fouling 'life' of the bottom composition used was not more than four months. This estimate agrees well with others derived from similar reconstructions; in fact, estimates of 'lives' of two to three months are not uncommon. Such estimates are also in agreement with those derived from studies of the rate of loss of poison from anti-fouling compositions (Barnes[7]).

Since most ships remain out of dry-dock for periods of eight months and over, it follows that they must be liable to foul for most of this period. Most of the ships involved in this survey had been painted with anti-fouling compositions made to war-time specifications for total poison content. Undue emphasis on the discrepancy between average anti-fouling 'life' under service conditions, and average length of service period, would therefore be unfair, but the 'life' of the paint would have to be approximately trebled to equal the *average* length of service period.

It cannot be too strongly emphasized that the absence of fouling at the end of a service period is not valid evidence of the effectiveness of the anti-fouling composition used. Such a result can be produced by the action of one or more of a number of factors which have no connection at all with the action of an anti-fouling composition. A ship may be unfouled when dry-docked if:

(*a*) It has operated in polar or temperate waters during the winter months, *i.e.*, settling stages have not been encountered.

(*b*) The periods in port have been short and the sea passages long.

(*c*) Calls have been made at fresh-water or scouring ports. (This factor is not invariable in its operation since a great deal depends upon whether the fresh-water or scouring port was visited near the beginning or towards the end of the voyage.)

(*d*) Fouling may have been lost during sea passages. Small barnacles die and are washed off, hydroid fouling may be lost (Hentschel[8]), and larger barnacles and oysters, killed by earlier unfavourable environmental conditions, may have disintegrated and have been washed away.

(*e*) Gross deterioration of the paint film may have occurred. This seems particularly likely during a maiden voyage and several cases in our records of new ships, 'clean' after an extensive period out of dry-dock, seem to be due to this cause.

Though these factors are effective in preventing permanent fouling settlement, to rely upon their operation involves an element of risk, since the shipowner must ensure that his vessels are so routed that such factors can operate. Though this may be done in certain cases, it is not normally an economic possibility. In his own interests, therefore, the shipowner should use an anti-fouling composition which is suitable for the routes that he operates and, what is at least equally important, he should ensure that the conditions of its application are such as to make its effective action possible.

Acknowledgments

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The Calculation of Stresses in the Ironing of Metal Cups

By R. Hill, M.A., Ph.D.

SYNOPSIS

The paper describes a theory of the stresses required to iron a cup by forcing it through a die with a close-fitting internal punch. It is assumed that the wall of the cup is thin enough for the deformation to be effectively plane strain. An accurate theory, based on a calculation of the slip-line field and the shape of the plastic region, is then available. The ironing load is evaluated for the practical range of reductions and die angles. Friction and work-hardening are taken into account.

Introduction

THE ironing process which is analysed in the present paper is one where the wall thickness of a metal cup is reduced while the internal diameter is kept constant. This is achieved by mounting the cup on a tightly fitting punch, and forcing it through a die chosen to give the required reduction (Fig. 1). The circumferential strain imparted to an annular element on the inside of the wall is then exactly zero, while it increases steadily for annular elements of increasing initial radius. If, however, the wall thickness is a sufficiently small fraction of the cup diameter, the circumferential strain is everywhere negligible compared with the component of strain resulting from the reduction in thickness. The problem may then be considered as one in which the deformation is essentially plane strain, thereby enabling the ironing process to be accurately analysed. This is the reason for the restriction that the internal diameter should not change. In practice, of course, the cup is often drawn to a new diameter while the wall thickness is being reduced. However, for purposes of a fundamental understanding of the process, it is also a practical, as well as a mathematical, convenience to consider pure ironing free from superimposed effects of drawing.

Previous theories of the stress distribution in ironing[1] are approximate, and are usually based on three main assumptions: (i) the deformation is a simple uniform extension, (ii) the principal stress directions are everywhere perpendicular and parallel to the punch surface, and (iii) the plastic region extends between the two transverse planes containing the circles of contact of cup and die at entry and exit. A satisfactory analysis, on the other hand, must automatically calculate the actual shape of the plastic region, and this can be determined only by considering the strains as well as the stresses. The distinction between the accurate and approximate solutions is not merely academic. Apart from the differences of principle, there are often considerable numerical differences between the respective estimates of the stresses, as is known from comparisons in other problems, *e.g.*, extrusion[2] and drawing.[3] The simple approximate theories under-estimate the work expended in plastic deformation by an amount corresponding to the non-uniform distortion not contributing directly to the final reduction in thickness. When the fractional reduction is small, the actual expenditure of work in ironing, as in drawing, may be as much as twice that estimated on the assumption of uniform extension.

In a recent paper by Hill and Tupper,[3] the stresses in wire-drawing were investigated by considering the analogous problem in two dimensions, where the metal could be regarded as being in the form of a wide sheet. It was shown that the stresses calculated for this plane-strain model closely approximated those

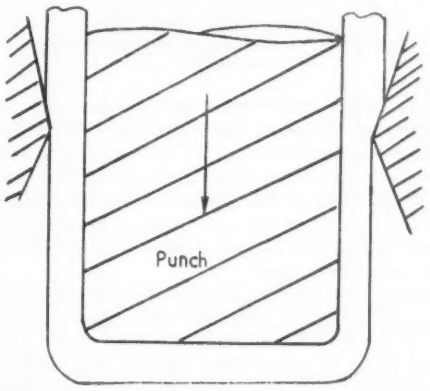

Fig. 1—Ironing of a thin-walled cup

measured in drawing wire, provided a simple conversion rule was employed. It so happens that the plane-strain analysis used in this approximate treatment of wire-drawing is also the accurate analysis for the problem of ironing. For, apart from a complication due to possible friction between the cup and the punch, it is apparent that the problems of sheet

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drawing and of ironing under conditions of plane strain are mathematically identical, with the central plane in the one replacing the surface of the punch in the other. As will be shown, friction on the punch makes little difference to the form of the solution, and the numerical results of Hill and Tupper are accordingly taken over for the present problem. For details of the derivation of the solution their original paper should be consulted ; reference here to equations or figures in their paper will be denoted by the letters H.T.

THE PLASTIC REGION IN IRONING

The die is supposed to be conical, with a total angle of 2α, and cut back sharply at exit. The effect of a parallel can be included if required, since it does not modify the form of the solution but merely adds to the load a term representing the frictional resistance in the parallel. In this example it is assumed that

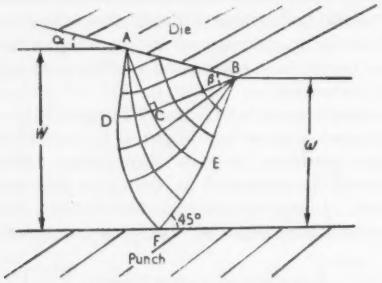

Fig. 2—Region of plastically deforming material

there is no friction between the cup and the punch, and also that the metal has a well-defined yield point and does not work-harden. (The inclusion of friction and work-hardening is described later.) The process is analysed during the period of steady conditions while the load is at its maximum. Consequently all stresses calculated in this paper correspond to the steady maximum load.

The region ABDEF of plastically deforming material is shown in Fig. 2, together with typical slip-lines (H.T. Fig. 1). This configuration applies for the normal range of reductions, but for large reductions the region of plastically deforming material intersects the inner surface over a finite length (H.T. Fig. 6*a*). If μ is the coefficient of die friction, the slip-lines meet the die in angles β and $90° - \beta$ where :

$$\cos 2\beta = \mu q'/K. \quad \text{.....(1)}$$

The pressure on the die surface is q' and, according to the theory, is uniform for the reductions in the range covered by the solution of Fig. 2. K is equal to $Y\sqrt{3}$, where Y is the yield stress in uniaxial tension. Outside ABDEF is a region where the material is stressed to the plastic limit, but is constrained to move as a rigid body by the surrounding non-plastic material. The rigid part of the plastic region does not need to be calculated, and so is not indicated in the figure. Its existence is due to the neglect of the elastic component of strain in the plastic region ; it represents what in a real metal would be a region where the plastic and elastic components of the strain are of comparable magnitude.

THE STRESSES IN IRONING

The load applied to the punch is transmitted to the base of the cup and is balanced by a tension in the wall. If L is the load, and t' the mean tensile stress in the thinned wall, then :

$$L = \pi w(d + w)t', \quad \text{.....(2)}$$

where w is the final wall thickness, and d is the internal diameter of the cup. Also (H.T. equation (7)) :

$$t' = (1 + \mu \cot \alpha)(W/w - 1)q', \quad \text{.....(3)}$$

where W is the initial wall thickness. W is supposed to be uniform, but in practice this will not usually be

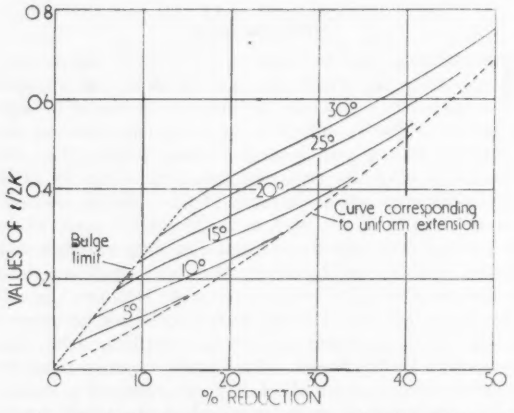

Fig. 3—Relation between mean tensile stress in ironed wall, and percentage reduction for various die half-angles

reliable, and fluctuations in the ironing load will be produced in consequence. The absolute reduction in thickness is $W - w$, and the fractional reduction, r, is defined in the usual way as :

$$r = 1 - w/W. \quad \text{.....(4)}$$

The error in applying equations based on plane deformation may be estimated by comparing the maximum circumferential strain with the strain involved in reducing the thickness. The former is approximately $2(W - w)/d$, whereas the latter cannot be less than $\log(W/w)$. Thus, for the practical range of reductions up to 50%, the circumferential strain is always about a fraction $2w/d$ of the strain due to the reduction in thickness. If d is not less than, say, $30W$, the plane-strain approximation may be regarded as good, though the theory will probably continue to give useful results for wall thicknesses up to a tenth of the cup diameter.

It was shown by Hill and Tupper[3] that, for coefficients of friction less than 0·2, the pressure q' on the die, when friction is present, is very little different from the pressure q on the die when the lubrication is perfect. Since the calculation of the exact value of q' for a range of values of μ, die angle, and reduction, is prohibited by the labour involved, it is advantageous

to introduce the approximation $q' \cong q$ in equation (3) and to write :

$$t' = (1 + \mu \cot \alpha)(W/w - 1)q = (1 + \mu \cot \alpha)t, \quad ..(5)$$

where t is the mean tension in the wall when the die is free from friction. Hill and Tupper calculated t for the range of reductions and angles normally used in practice. The graph of $t/2K$, as a function of the percentage reduction ($100r$) for various die half-angles, is reproduced in Fig. 3. The lower limit on each curve represents the percentage reduction, below which theory predicts the formation of a bulge or standing wave in the metal surface about to enter the die.

The main point, emphasized by the results in Fig. 3, is that the simple theories (which assume the deformation to be a uniform extension) under-estimate the load by an amount which becomes increasingly large as the fractional reduction is decreased. In contrast, the value $t = 2K \log(1/1 - r)$ for the tensile stress, given by the simple theory, provides a useful approximation where sufficiently large reductions are concerned.

Combining equations (2) and (5) :

$$L = \pi w(d + w)(1 + \mu \cot \alpha)t, \quad \ldots\ldots\ldots \quad (6)$$

where t is to be read from Fig. 3. It is customary in ironing practice to regard L as a function of the absolute reduction for a given initial wall thickness. The initial cross-sectional area of the wall is approximately πdW, and, for the present purpose, $L/2\pi dWK$ may be taken as a non-dimensional measure of the load. To a sufficient approximation :

$$L/2\pi dWK = (1 + \mu \cot \alpha)(1 - r)t/2K \ldots\ldots\ldots(7)$$

For a perfectly lubricated die $L/2\pi dWK$ is shown in Fig. 4 as a function of r, using values of t from Fig. 3. Since the initial thickness is being held constant, r is a suitable non-dimensional measure of the absolute reduction. The curve $(1 - r)\log(1/1 - r)$ is included ; this represents the load estimated by the simple theory, which is approached by the accurate theory at large reductions. The curve reaches a maximum value of $1/e$ (*i.e.*, 0·368) for a fractional reduction $1 - 1/e$ (*i.e.*, 0·632), where e is the exponential constant. Also shown is the locus, $t = 2K$, corresponding to yielding of the ironed wall in tension (for a non-hardening metal only) ; the locus intersects the lower curve at its maximum.

As an empirical formula, sufficiently accurate for practical use, the curve for each die angle could be roughly replaced by a straight line with a slope and ordinate intercept depending on the die angle. It is important to realize that this approximate linear relationship applies only in the range covered by the present solution, and cannot be generally applicable, since all the curves must ultimately pass through a maximum and return to zero. Also, at small reductions bulging intervenes and raises the load considerably. The linear relationship can be written as :

$$L/2\pi dWK = a + br,$$

where a and b are non-dimensional functions of the die angle ; a is the apparent intercept on the ordinate axis.

Alternatively : $L = A + B(W - w)$, ...(8)

where $A = 2\pi dWKa$ and $B = 2\pi dKb$. For a given initial wall thickness the ironing load thus varies in an approximately linear manner with the absolute reduction over a limited range. It will be noticed that for a given die angle, A is proportional to the initial cross-sectional area of the wall ; for a given reduction A increases, and B decreases, as the die angle is raised. The effect of die friction is simply to multiply A and B by the corresponding value of $1 + \mu \cot \alpha$, without affecting the accuracy of the linear relationship. The curves for different die angles now cross, implying that for a given coefficient of friction there is an optimum die angle at which the load, to achieve a given reduction, is a minimum (H.T. Figs. 9 and 10). The optimum half-angle, measured in degrees, was calculated by Hill and

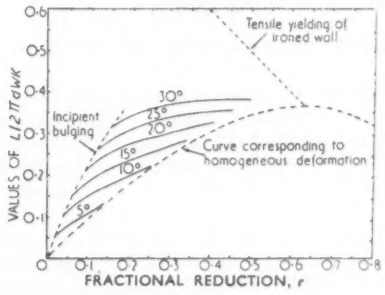

Fig. 4—Load-reduction relation for various die half-angles. (No hardening and no friction)

Tupper to be roughly forty times the fractional reduction for coefficients of friction between 0·05 and 0·15.

ALLOWANCE FOR WORK-HARDENING

A simple correction for work-hardening, to be applied to the preceding results, has been described by Hill and Tupper. Suppose the relation between true stress and logarithmic strain has been obtained from a tensile test* on the material in the same state as the material of the cup immediately before ironing. The equivalent tensile strain imparted by ironing may be taken to be $2/\sqrt{3}$ multiplied by the ordinate of Fig. 3 at the reduction and angle concerned. The yield stress of the worked material after ironing is then equal to the ordinate of the tensile curve at this equivalent strain. The mean tensile stress in the wall, after ironing with a *frictionless* die, is equal to the area under the tensile curve up to the equivalent strain. It is evident that this implies that annealed material can be given a greater reduction than worked material, without the risk of failure of the ironed wall. To allow for die friction the calculated tensile stress must be multiplied by the factor $1 + \mu \cot \alpha$.

The modification to Fig. 4, which work-hardening introduces, can best be understood by reference to a particular example. Assuming that the material has been previously cold-worked and that its yield

* Or estimated by some more convenient method.

point is Y and also that the rate of hardening is a constant over the range of strain under consideration, the tensile stress/strain curve will have the equation :

$$Y' = Y + H\epsilon,$$

where ϵ is the logarithmic strain, and H is the constant rate of hardening. The mean tensile stress in the ironed wall is then :

$$(1 + \mu \cot \alpha)(Y + \tfrac{1}{2}H\epsilon)\epsilon,$$

where ε is $2/\sqrt{3}$ multiplied by the appropriate ordinate of Fig. 3. Hence the ironing load is :

$$L = \pi dW(1 + \mu \cot \alpha)(1 - r)t(1 + Ht/6K^2). \quad ...(9)$$

This differs from equation (7) by the factor $1 + Ht/6K^2$, which increases with both reduction and die angle. The general tendency of this factor is to increase the slopes of the curves, without affecting the rough linear approximation.

INFLUENCE OF FRICTION BETWEEN CUP AND PUNCH

The base of the cup, and that part of the ironed wall which has been unloaded, move away from the die with the speed of the punch. Frictional forces will not, therefore, be induced over the section of the inner wall to the right of F in Fig. 2. To the left of F the punch moves faster than the wall, and frictional forces there resist the movement of the punch and contribute to the ironing load. These forces arise from the radial reaction transmitted from the die through the wall ; they are presumably distributed all along the wall to the left of F, though probably mainly in a region near the die. So long as the coefficient of friction is not too large, it can be expected that only the rigid parts of the plastic region outside ABDEF (Fig. 2) will be affected. The slip-lines ADF and BEF continue to intersect the surface at F at 45°, since the frictional stress is zero there. The wall approaching the die is pulled by the frictional force exerted by the punch, which is equivalent, as regards conditions in ABDEF, to a negative back tension applied to the cup. If the die is perfectly lubricated, the effect of a negative tension is simply to add a uniform hydrostatic pressure to the plastic stresses already calculated ; the slip-line field is unaltered. This is true whether the material work-hardens or not. The pressure on the die is raised, and the mean tensile stress in the ironed wall lowered, by the value of this uniform pressure. Hence if F is the total frictional force, the tensile load exerted by the base of the cup on the ironed wall is lowered by an amount Fw/W. The load on the punch is therefore raised, not by the full value F of the friction, but only by the amount $F(1 - w/W) = Fr$.

If, on the other hand, die friction is present, the angle β (Fig. 2) changes with the pressure on the die, and the slip-line field is accordingly altered. The effect would be too complicated to follow accurately by a recalculation of the slip-line field, but an approximate estimate of the new tension in the ironed wall can easily be made. For this purpose it is supposed, as before, that the pressure on the die is virtually unaltered by the die friction. If t denotes the mean tensile stress when there is no friction on either die or punch, the normal pressure on the die is $tw/(W - w)$. When there is friction on the punch, but not on the die, the pressure is increased by the amount F/W, as has been seen. When friction is present on both die and punch, simple considerations of equilibrium show that the tensile load exerted by the base of the cup is, according to the previous assumption,

$$-F + (1 + \mu \cot \alpha)(wt + Fr),$$

where μ is the coefficient of friction on the die. Hence the friction on the punch decreases the load on the base of the cup by :

$$F[1 - r(1 + \mu \cot \alpha)]. \quad .....(10)$$

The load on the punch is thus increased by a fraction $r(1 + \mu \cot \alpha)$ of the frictional force between the cup and the punch.* It would be very difficult to calculate F because the normal reaction between the surfaces of cup and punch in relative motion depends, among other things, on the elastic distortion of the wall. This determines the relative fractions of the reaction on the die that are transmitted through the wall in front of, and behind the die, respectively. It is best to regard F as an unknown parameter to be determined experimentally.

It should, perhaps, be added that a further complication arises in the accurate theory when the reduction is outside the range covered by the solution of Fig. 2. The region of plastically deforming material then extends along a finite length of the inner surface. Consequently, when friction is present, the angles at which the slip-lines intersect the inner surface are altered, and with them the whole of the slip-line field. But in this case also, the approximate estimate of the influence of the punch friction should be equally applicable.

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* A similar analysis applied to wire-drawing would lead to the same value of the back-pull factor, with r as the fractional reduction in area. The argument is quite general, and makes only the one assumption about the pressure on the die. Also, the degree of approximation is known in special cases from the accurate theory. The formula is therefore preferable to estimates based on extensions of the simple theory of Sachs.

References

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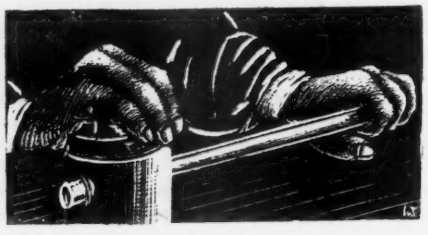
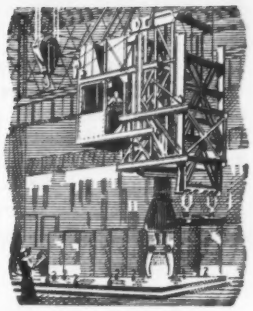
2. R. HILL : *Journal of The Iron and Steel Institute*, 1948, vol. 158, Feb., pp. 177–185.
3. R. HILL and S. J. TUPPER : *Ibid.*, 1948, vol. 159, Aug., pp. 353–359.



IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



DESCRIPTION OF NEW PLANT

Automatic Loading Controller

UNTIL recently, the burden from a 2-strand pig-casting plant had been loaded into wagons of various capacities, the load being dependent upon the experience and judgment of the plant operator. This method, for various reasons, led to the wagons being overloaded to such an extent that they were unacceptable by the railway authorities. A counting and indicating device, which is simple in construction and operation, has been designed at the Margam Works of the Steel Company of Wales, Ltd., for use in controlling the loading of wagons with any type of uniform burden, and to facilitate the even distribution of such loads.

The unit comprises electrical-counting and indicating apparatus, with a feed switch actuated by each unit of load entering the wagon or introductory conveyance, a uni-selector device which is stepped forward by feed-switch actuations, and an indicator device which shows when a predetermined full load has entered. Where a full load corresponds to a relatively large number of feed-switch actuations, the uni-selector device comprises primary and secondary switches, the primary switch being stepped forward by the feed switch, and is so arranged that it steps forward the secondary switch at the end of each full sequence.

Means are provided so that the indicator may be operated at any one of a number of predetermined positions in the range of the secondary uni-selector switch corresponding to the full loadings of various sizes of wagons. The device may also be arranged to indicate when a predetermined fraction of the full load (say, half) has been reached, thus enabling the loading position in the wagon to be changed so as to secure a substantially uniform distribution of load. A warning can also be given when the delivered load is a predetermined amount (say, one ton) short of the selected full load.

OPERATION

An example of the practical operation of the automatic loading controller, for use with the pig-casting plant, is to be found at the Steel Company of Wales, Ltd., Margam Works, South Wales, where the pigs are carried in their moulds to a chute, through which they drop for delivery into wagons berthed in turn underneath. Each " stream " of pigs is known as a strand, and provision is made for feeding the chute with two strands, which can be operated together or singly. Associated with each strand is a striker-operated gravity-return switch, actuated by the strand-link trunnions, once for every two pigs carried by the strand. The delivery of pigs from the chute is controlled so that the flow can be temporarily stopped while a fresh empty wagon is being berthed, or when a half-loaded one is being moved along to receive the remainder of its load; the control is operated electrically by two chute relays, the delivery being stopped when either of the relays is energized.

SELECTOR CONTROL

The controller itself, which is a compact instrument, as shown in Fig. 1, is contained within a dust-proof casing, has socket connections for conductors leading to the two strand switches, a 24-volt D.C. power supply, and chute control gear. The instrument includes a primary uni-selector switch which has two banks of contacts, and a selector which is stepped round electromagnetically. There is also a secondary uni-selector switch which is similar, except that it has three banks of contacts. The primary switch has its operating magnet connected in series with the current supply (for which there is an on–off switch on the instrument) and a two-way selector switch that brings in one or other of the strand switches. When only one strand is working, this two-way selector switch is set to the corresponding position, but when both are working, its position is immaterial. In this way the primary uni-selector is arranged to make a complete cycle in six steps, if both strands are working, or twelve steps when only one strand is in action (since each closure of either strand switch

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corresponds to four pigs on two strands, or two pigs on only one strand, as previously mentioned).

An on–off switch, shorting-out some of the contacts of the first bank on the primary uni-selector switch, is provided, and is closed when the two strands are working. The second bank only makes contact at the end of each cycle of the switch, and it is connected in circuit with the operating electromagnet of the secondary uni-selector switch, so that the latter is stepped forward as each ton is delivered into the chute. The secondary switch operates in conjunction with a wander-plug device which is set to suit the full capacity of the wagon being loaded.

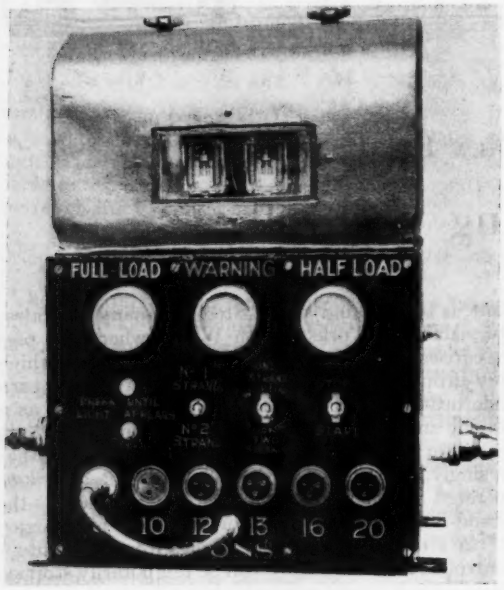


Fig. 1—Control panel of Automatic Loading Controller

LOADING CONTROL

The instrument is adapted to load in separate steps, different-sized wagons having capacities of 8, 10, 12, 13, 16, 20, and up to 60 tons, and is provided on the front with a series of six three-pin sockets, any one of which is adapted to receive a three-pin wander-plug on a flexible three-core conductor lead. The selectors on banks 1 and 2 of the secondary uni-selector switch are connected to the positive pole of the supply so that the contacts of these two banks are made " alive " in sequence, one at a time, as the successive tons of pig-iron pass into the chute. Appropriate contacts from these banks are connected to the wander-plug sockets so that each of these is made alive as the corresponding loading is reached. For convenience, the first bank is used for half-load and " warning " (*i.e.*, one ton less than full load), while the second bank is used for full load. For example, if the first three-pin socket is for a wagon holding 8 tons, the left-hand pin-socket is connected to the fourth contact on bank 1 (half-load), the upper pin socket to the seventh on bank 1 (warning—1 ton less than 8) and the right-hand pin-socket is connected to the eighth on bank 2 (full load). The half-load for the 13-ton wagon is taken as 7 tons.

INDICATORS

Three coloured lamps are used as indicators, white for half-load, red for warning, and green for full-load. Each has one pole connected to the negative supply, and its other pole connected to the appropriate pin of the wander-plug (*i.e.*, white to the left-hand, green to the right-hand, and red to the upper pin.) Two relays, with their contacts paralleled in the chute-control circuit, have their coils connected to the negative supply from the right-hand and left-hand pins respectively; thus, whenever the white or green lamps light up (for half-load and full-load, respectively), the chute is closed. By inserting a wander-plug into the socket corresponding to the size of the wagon, the indicator lamps are automatically connected to the appropriate contacts of the secondary uni-selector switch, and are actuated automatically as the delivered load reaches the half-load warning and full-load values.

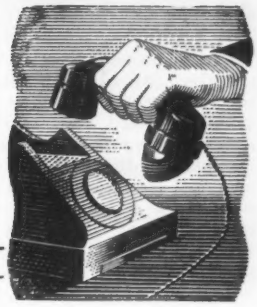
The third bank of the secondary uni-selector switch is used for re-setting the switch to its starting position, after each wagon has been loaded. Its contactor is connected to the positive supply by means of a re-setting switch of the bell-push type, a re-set indicating lamp being connected to the starting contact of bank 2, and to the negative supply, so as to light when the secondary switch reaches its starting position. After each wagon has been filled the re-setting switch is pressed until the re-set indicating lamp lights; if necessary, the wander-plug is changed to the appropriate socket, and the instrument is ready for the next loading.

The success of the practical application is best illustrated by the following results assessed during preliminary trials:

Old Method		Improved Method	
Wagons in 'string' selected	Wagons overloaded	Wagons in 'string' selected	Wagons overloaded
10	8	7	All correct
5	3	7	1
6	4	8	All correct
16	11	8	1
8	5	14	All correct
8	5	8	All correct
7	4	8	2
60	40 (66·6%)	60	4 (6·6%)

Since these results were recorded, further adjustments have been made, and the overload percentage figures are now practically nil. Maintenance of the apparatus has been provided for by making all moving parts easily accessible. This is done simply by removing the two wing nuts at the top of the device. Patents for the Controller have been applied for.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting, 1949

The Annual General Meeting of The Iron and Steel Institute will be held in London on Wednesday and Thursday, 27th and 28th April, 1949. A Luncheon for Members is to be arranged for Thursday, 28th April, 1949.

NEWS OF MEMBERS

▶ Mr. P. BAKER has resigned his position as metallurgical chemist in the Central Research Department of British Ropes, Ltd., to become a technical trainee in the company's Doncaster works.

▶ Mr. C. D. BARLOW has been appointed Chairman of Beard Electrical, Ltd., Great Bridge, Staffs.

▶ Mr. DONALD J. BLICKWEDE has been awarded the degree of Doctor of Science by the Massachusetts Institute of Technology.

▶ Mr. JOHN M. BOXALL has been awarded the degree of B.Sc. in metallurgy, and the A.R.S.M. with first-class honours. He has now taken up a position with the National Smelting Company, at Avonmouth, as a metallurgist in the Research Department.

▶ Mr. M. W. BUTTLER has left the English Steel Corporation, Ltd., and is now with the British Iron and Steel Research Association, as a metallurgist in the Steel-making Division.

▶ Mr. T. EDGE, formerly chief metallurgist at Crossley Motors, Ltd., is now a metallurgist at the Department of Atomic Research, Risley, Warrington.

▶ Mr. W. EVANS has left University College, Swansea, and has been appointed senior examiner at the A.I.D. Test House, Harefield, Middlesex.

▶ Mr. C. W. GUNNEE has left Messrs. Dorman, Long and Co., Ltd., Middlesbrough, and is now with the Fuel Department at the Ministry of Supply Barrow Works, Barrow-in-Furness.

▶ Mr. JAN GWOREK is now on the staff of the Research Laboratory of Messrs. John G. Stein and Co., Ltd.

▶ Mr. LAURENCE J. A. HAYWOOD, chief chemist of Messrs. Catton and Co., Ltd., Yorkshire Steel Foundry, Leeds, has been appointed chief chemist and metallurgist of the company, in charge of steel manufacture, treatment, and analysis.

▶ Mr. R. M. JONES, formerly at Cambridge University, is now an assistant technical officer with I.C.I., Ltd., Metals Division, Birmingham.

▶ Dr. D. S. LAIDLER has left Wild-Barfield Electric Furnaces, Ltd., to take up an appointment as assistant research manager of Goodlass Wall and Lead Industries, Ltd., at Greenford, Middlesex.

▶ Mr. K. RAY is now Director of Inspection, D.G.I. and S., at New Delhi, India.

▶ Mr. H. A. SNOW, formerly research and development engineer at the International Wire Co., Ltd., is now a Director of Messrs. E. L. Forge and Partners, Ltd., Consulting and Development Engineers, of London, W.1.

▶ Mr. D. E. J. TALBOT has joined the staff of the metallurgical Branch of the Armaments Research Establishment, Royal Arsenal, Woolwich, as a research metallurgist.

▶ Mr. W. J. THOMAS has been awarded the degree of B.Sc. with first-class honours in metallurgy. He has now left University College, Swansea, and is with I.C.I., Ltd., Metals Division, at Waunllwyd, Gowerton, Glam.

▶ Mr. ASHLEY S. WARD, who has been for many years Chairman of the Ketton Portland Cement Co., Ltd., has retired from the Board and has been succeeded by Mr. Frank R. Stagg, who now holds the position of Chairman and Joint Managing Director. Other changes on the Board of this Company include the appointment of Mr. RAWSON F. STAGG, as Joint Managing Director, and Mr. F. W. ROBINSON as a Director.

▶ Mr. T. K. WARIER is now Assistant Director of Inspection (Met.) at the Ministry of Industry and Supply, Tatanager, India.

▶ Mr. L. H. WILLIAMS has left the research staff of the Imperial Smelting Company and has joined the editorial staff of *Iron and Coal Trades Review*.

Obituary

The Council regret to record the deaths of :

Mr. JAMES A. CORDER, on 23rd October, 1948.

Mr. A. SMITH, of West Bromwich, on 31st October, 1948, aged 70.

NEWS OF SCIENCE AND INDUSTRY

Fourth Empire Mining and Metallurgical Congress

The response to the first circular issued in connection with the Fourth Empire Mining and Metallurgical Congress, to be held in Great Britain from 9th to 23rd July, 1949, has been somewhat greater than was originally expected. Members who wish reservations to be made for them, and who have not already done so, are therefore requested to complete and return Form A of the Circular as soon as possible so that reservations may be made accordingly. Correspondence should be addressed to the General Secretaries, Fourth Empire Mining and Metallurgical Congress, 436, Salisbury House, Finsbury Circus, London, E.C.2.

Members are also reminded that the second and subsequent circulars will be sent only to those who have replied to the first circular.

Beilby Memorial Awards

From the interest derived from the invested capital of the Sir George Beilby Memorial Fund, at intervals to be determined by the administrators representing the Royal

Institute of Chemistry, the Society of Chemical Industry, and the Institute of Metals, awards are made to British investigators in science to mark appreciation of records of distinguished work. Preference is given to investigations relating to the special interests of Sir George Beilby, including problems connected with fuel economy, chemical engineering, and metallurgy, and awards are made, not on the result of any competition, but in recognition of continuous work of exceptional merit, bearing evidence of distinct advancement in science and practice.

In general, awards are not applicable to workers of established repute, but are granted as an encouragement to younger men who have done original independent work of exceptional merit over a period of years.

Consideration will be given to the making of an award or awards from the Fund early in 1949, and the administrators—the Presidents, Honorary Treasurers, and Secretaries of the three participating institutions—will be glad to have their attention drawn to outstanding work of the nature indicated.

All communications on this subject should be addressed to the Convener, Sir George Beilby Memorial Fund, Royal Institute of Chemistry, 30, Russell Square, London, W.C.1.

Inter-Service Metallurgical Research Council

The Admiralty and the Ministry of Supply have set up an Inter-Service Metallurgical Research Council to advise them on metallurgical problems of importance to the Services. The independent members are : Professor L. Aitchison (Chairman), Professor E. N. da C. Andrade, F.R.S., Professor G. Wesley Austin, O.B.E., Mr. G. L. Bailey, Dr. R. W. Bailey, Mr. H. H. Burton, Dr. W. Hume-Rothery, F.R.S., Dr. H. Moore, C.B.E., Mr. A. J. Murphy, Mr. D. A. Oliver, Dr. C. J. Smithells, Dr. C. Sykes, F.R.S., and Dr. W. H. J. Vernon, O.B.E. The Secretary is Mr. A. H. Waterfield.

Institution of Polish Engineers in Great Britain

The Stowarzyszenie Technikow Polskich w Wielkiej Brytanii (Association of Polish Engineers in Great Britain) has changed its name to " Institution of Polish Engineers in Great Britain." The offices and library of the new Institution are at 146, Holland Road, London, W.14.

Memoranda

▶ Petroleum Information Bureau and the Petroleum Films Bureau have changed their address to 29, New Bond Street, London, W.1 (telephone : Regent 7565 and 6308).

▶ Messrs. F. A. Hughes and Co., Ltd., have changed their address to Bath House, 82, Piccadilly, London, W.1 (telephone : Grosvenor 6300).

▶ Tinsley (Industrial Instruments), Ltd., previously at South Norwood, London, S.E.25, have changed their address to North Circular Road, West Twyford, London, N.W.10 (telephone : Elgar 6081).

DIARY

17th Jan.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—" *The Automatic Control of Open-Hearth Furnaces*," by T. Land—Royal Victoria Station Hotel, Sheffield, 6.15 P.M.

19th Jan.—MANCHESTER METALLURGICAL SOCIETY—" *Metallography of Stainless and Heat-Resisting Steels*," by J. I. Morley—Engineers' Club, Albert Square, Manchester, 6.30 P.M.

20th Jan.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—Film on " *Aluminium from Ore to Finished Product*"—Whitehead Institute, Cardiff Road, Newport, Mon., 7.0 P.M.

21st Jan.—INSTITUTE OF METALS (Sheffield Local Section)—" *Thermocouples* " by R. C. Jewell—Grand Hotel, Sheffield, 6.30 P.M.

21st Jan.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—" *A Statistical Investigation of Cracking in Basic Open-Hearth Ingots*," by I. M. Mackenzie—39, Elmbank Crescent, Glasgow, 6.45 P.M.

25th Jan.—INSTITUTION OF ELECTRICAL ENGINEERS—Discussion on " *Improved Methods of Meter Testing* " —Institution of Electrical Engineers, Savoy Place, London, W.C.2, 5.30 P.M.

27th Jan.—MIDLAND METALLURGICAL SOCIETIES—" *Symposium on Clad Metals*," by F. R. Pattison and L. B. Hunt—James Watt Institute, Great Charles Street, Birmingham, 6.30 P.M.

29th Jan.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Annual Dinner.

2nd Feb.—MANCHESTER METALLURGICAL SOCIETY (Joint meeting wih The Iron and Steel Institute)—" *Precipitation-Hardening Effects in Relation to High-Temperature Testing*," by J. Glen—Engineers' Club, Albert Square, Manchester, 6.30 P.M.

3rd Feb.—LEEDS METALLURGICAL SOCIETY—" *The Function of Ductility in Design*," by R. W. Bailey—Chemistry Department, the University, Leeds, 7.0 P.M.

3rd Feb.—LIVERPOOL METALLURGICAL SOCIETY—" *Metallurgical Developments Connected with Heat Treatment of Steels in Salt Baths*," by F. D. Waterfall—9 The Temple, 24 Dale Street, Liverpool, 7.0 P.M.

3rd Feb.—MIDLAND METALLURGICAL SOCIETIES—James Watt Institute, Great Charles Street, Birmingham, 6.30 P.M.

5th Feb.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY (Joint meeting with the Institute of British Foundrymen)—" *Steel Castings*," by J. E. Mercer—Newport Technical College, 6.30 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the December, 1948, issue of the *Journal*, p. 434.)

TRANSLATIONS AVAILABLE

No. 367 (German). O. KRIFKA and F. RAPATZ : " The Deoxidising and Desulphurising Slag-Reaction Process." (*Verein deutscher Eisenhüttenleute, Düsseldorf, Confidential Report No.* 77 (1944).)

No. 368 (German). T. KOOTZ : " On the Question of the Effect of Converter Shape on the Nitrogen Content of Steel. (The " Converter Characteristic.") (*Verein deutscher Eisenhüttenleute, Düsseldorf, Confidential Report No.* 72 (1944).)

No. 369 (German). (*a*) G. NAESER : " The Development of a Process for the Manufacture of High-Quality Basic Bessemer Steel (MA Steel)". (*Verein deutscher Eisenhüttenleute, Düsseldorf, Confidential Report No.* 67 (1944).)

(*b*) W. BADING : " Production of Hot-Blown, Low-Nitrogen Steel." (*Verein deutscher Eisenhüttenleute, Düsseldorf, Confidential Report No.* 67 (1944).)

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

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Alloy Casting Bulletin (New York)
Alloy Metals Review (Widnes, Lancs.)
Alluminio (Milan)
Aluminium Courier (London)
Aluminium Development Association (London)
Information Bulletin
Aluminium Laboratories, Ltd. (Montreal)
Abstract Bulletin
American Bureau of Metal Statistics (New York)
Yearbook
American Ceramic Society (Columbus, Ohio)
Bulletin
Journal
American Chemical Society (Washington, D.C.)
Journal
American Electroplaters' Society (Jenkintown, Pa.)
Proceedings
American Foundryman (Chicago)
American Foundrymen's Society (Chicago)
Transactions
American Gas Association (New York)
Monthly
Natural Gas Department, Proceedings
Proceedings
American Gas Journal (New York)
American Institute of Electrical Engineers (New York)
Transactions
American Institute of Mining and Metallurgical Engineers (New York)
Blast-Furnace and Raw Materials Committee, Proceedings
Contributions
Electric Furnace Steel Conference, Proceedings,
National Open-Hearth Committee, Proceedings
Technical Publications
Transactions
American Iron and Steel Institute (New York)
Annual Statistical Reports
Contributions to the Metallurgy of Steel
National Emergency Steel Specifications.
Statistical Bulletin
Yearbook
American Journal of Physics (New York)
American Journal of Science (New Haven, Conn.)
American Petroleum Institute (New York)
Proceedings, Production Section
American Society of Civil Engineers (New York)
Proceedings
Transactions
American Society of Mechanical Engineers (New York)
Transactions
American Society for Metals (Cleveland, Ohio)
Review of Metal Literature
Transactions
American Society for Naval Engineers (Washington, D.C.)
Journal
American Society for Testing Materials (Philadelphia)
Bulletins
Proceedings
Standards
Symposia
American Water Works Association (New York)
Journal
American Welding Society (New York)
Miscellaneous Publications
American Zinc Institute (New York)
Journal
Anales de Fisica y Química (Madrid)
Anales de Ingeniería (Bogota, Colombia)
Anales de Mecanica y Electricidad (Madrid)
Analyst (London)
Analytica Chimica Acta (New York and Amsterdam)
Analytical Chemistry (Washington, D.C.)
Angewandte Chemie (Ausgabe B) (Weinheim, Germany)
Anglo-Swedish Review (London)
Annales des Mines (Paris)
Documentation
Mémoires

LIST OF PERIODICALS

Applied Mechanics Review (New York)
Applied Scientific Research (The Hague)
Archiv für Metallkunde (Heidelberg and Berlin)
Archives des Sciences Physiques et Naturelles (Geneva)
Arkiv for Kemi, Mineralogi och Geologi (Stockholm and Upsala)
Asociación Química Argentina (Buenos Aires)
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Association des Industriels de Belgique (Brussels)
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Australasian Institute of Mining and Metallurgy (Melbourne)
Proceedings
Automobile Engineer (London)

BEAMA Journal (London)
B.H.P. Review (Melbourne)
Ball Bearing Journal (Luton)
Báňsky Obzor (Prague)
Bányászati és Koházati Lapok (Budapest)
Battelle Memorial Institute (Columbus, Ohio)
Miscellaneous Publications
Bell Laboratories Record (New York)
Bell System Technical Journal (New York)
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Berg- und Hüttenmännische Monatshefte (Vienna)
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Birmingham Metallurgical Society (Birmingham)
Journal
Blad för Bergshandteringens Vänner (Stockholm)
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Board of Trade (London)
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Separaats
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FUEL—PREPARATION, PROPERTIES, AND USES

Steam Boilers and Stoking for High-Ash Fuels. A. Zinzen. (Die Technik, 1948, vol. 3, Aug., pp. 337–340). The present state of development of power-station boilers in Germany and means of getting the optimum results from high-ash coal are discussed. A chain grate for firing brown coal is described.—R. A. R.

Notes on Burning Low Grade High-Ash Coal in Wet-Bottom Boilers. R. Doležal. (Strojnický Obzor, 1946, vol. 26, Oct., pp. 198–210; Nov., pp. 211–215). [In Czech]. High-ash coal is generally burned in pulverized form. This is advantageous, because an indirect effect of the grinding process is the breaking up of the coal into some particles with very low ash content and others very high in ash up to 100%; this causes a considerable reduction of the losses due to enclosure of combustible particles inside slag particles. In most cases it is very economical to burn high-ash fuel in slagging furnaces, as the ignition of the fuel is ensured in these furnaces owing to the high flame temperature and intense heat radiation from the slag layer on the furnace bottom; the high temperature of the preheated combustion air favourably affects the burning of the individual coal particles. The melting of large quantities of slag permits transformation of the slag into a non-dusty and usable material.

A considerable amount of heat is consumed for heating and melting the slag particles. Granulation in water does not permit economical utilization of the heat in the slag, but this heat could be utilized if a slag-granulation process could be developed which would heat the air for combustion. Preheating combustion air is very important because it permits burning of coal with low calorific value and high ash, and, with a slagging furnace, coal having ash of a high melting point can be burned. The resulting high flame temperature also improves the combustion of the coal particles, and, because of the increased temperature, the thickness of the solid slag layer decreases causing an increased heat transfer through the furnace wall. It is important to place the air heater immediately behind the slagging furnace walls where the temperature is highest in order to obtain maximum heat radiation because at such high temperatures heat transfer by convection is relatively unimportant. The function of the refractory lining of the walls is not a very important factor in furnaces designed to burn high-ash coal, because the heat transfer coefficient of the furnace wall is mainly dependent on the rate of slag deposition when the mean flame temperature does not exceed 1800° C. The thickness of the slag layer on the furnace bottom is very much larger than the layer

adhering to the walls, thus providing good insulation. For a slag layer 150 mm. thick the temperature of the boundary layer of the refractory lining is only about 50° C. higher than that of the water in the cooling tubes, and occurrence of steam bubbles in case of stopped water circulation will not cause tube failures by local overheating.—E. G.

Air-Cooled Slagging Furnaces and Their Importance for Burning Inferior Grades of Coal. R. Doležal. (Technik, 1947, vol. 5, No. 8–9, pp. 246–248; No. 10, pp. 274–277). [In Slovakian]. The trend of modern boiler development is to find suitable methods for utilization of the lowest grades of coal containing over 60% of high-melting-point ash. In order to maintain the stability of the flame at high temperatures and to permit processing and removal of large quantities of slag it is necessary to use slagging furnaces. According to the author it would be possible to utilize coal with up to 80% ash in air-cooled slagging furnaces. The combustion process for high-ash pulverized coal is practically the same as for low-ash pulverized coal. The fine ash particles separating the individual coal particles increase the heat radiation of the flame and cause slight delay in the ignition of the mixture. The ash also absorbs heat and reduces the useful heat output of the furnace. In water-cooled slagging furnaces there is a definite limit to the ash content of utilizable fuel and this limit is lower the higher the melting point of the ash. Above a certain ash content uncooled slagging furnaces do not operate satisfactorily, because the slag particles do not reach their melting temperatures quickly enough and the viscosity of the liquid slag is too high. The only suitable solution for burning coal of very high ash contents is to cool the slagging furnaces by preheated combustion air, whereby the temperature of this air is increased from 400° to 880° C., thus reducing considerably the delay in igniting the coal particles. The refractory walls separating the combustion from the cooling space is protected from the liquid slag by reducing its surface temperature below the slag fusion point, thus permitting formation of a solid slag layer which prevents contact between the liquid slag and the refractory lining. To keep down the temperature of the refractory surface it is necessary to have a high coefficient of heat transfer from the wall to the cooling air, to see that the ash content, and thus the thickness of slag deposit on the walls, are sufficiently high, and that the slag melting point is high enough. The last two properties are required to obtain a sufficiently thick slag deposit on the furnace walls. Radiation plays a very important part in the heat transfer from the wall to the cooling air of the slagging furnace; in one case the heat transfer was increased from about 60 to about 94 kg.cal./sq. m./° C./hr. By inserting an intermediate wall in the air duct the cooling effect is intensified and, in the above example, the temperature of the boundary layer between the refractory and the solidified slag was reduced by a further 100° C. and the heat transfer increased to 116 kg.cal./sq. m./° C./hr., thus increasing the air temperature to 880° C. These values were obtained for coal the slag from which had a viscosity of 1000 Poise at 1460° C., and 100 Poise units at 1510° C. To obtain the required air temperature of 880° C. for a boiler output of 125 tons/hr. of steam at 65 kg./sq. cm. pressure and 500° C., a surface of about 190 sq. m. would be required, *i.e.*, a chamber of about 6 × 6 × 8 m., which is about equal to or slightly larger than a water-cooled slagging furnace of the same output.—E. G.

New Values and Formulae for the Radiation of the Products of Combustion. A. Schack. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 11–16). The results of investigations by H. C. Hottel and R. B. Egbert on the emissivity of carbon dioxide and steam at temperatures up to 2000° C. are applied to the plotting of emissivity curves and the derivation of formulæ.—R. A. R.

Heat Transfer in Heat Exchangers. T. Brandin. (Teknisk Tidskrift, 1948, vol. 78, Oct. 16, pp. 663–665). [In Swedish]. A rapid method of making heat-transfer calculations for heat exchangers with sufficient accuracy for practical purposes is explained.—R. A. R.

The Requirements of Heat Economy and Measures for Saving Fuel with Special Reference to Powerstation Operation. H. Koppe. (Die Technik, 1948, vol. 3, Aug., pp. 341–344).

Preheating of Fuel in Shaft Furnaces and Gas Generators. B. V. Kantorovich. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques, 1948, Jan., pp. 43–52).

Determination of the Electrical Resistance of Coals and Shales. A. A. Agroskin and I. G. Petrenko. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 807–812). [In Russian]. Experimental investigations are described in which the electrical resistance of samples of coals and shales, under a surface pressure of 0·5 kg./sq. cm., was determined in the range room temperature to 900° C. with a rate of heating of 3°/min. The results obtained are shown in the form of curves of the logarithm of the specific resistance against temperature in which three distinct phases are distinguishable: (1) Up to 200° C., where the moisture content of the sample has a predominating influence; (2) from 200° to 800° C., where the greatest diminution in resistance occurs; and (3) above 800° C., where the diminution becomes very small. The change in the magnitude of the specific resistance on heating from room temperatures to 900° C. was, in most cases, from 10^{10}–10^{9} Ω cm. at the former, to 10^{2}–10 Ω cm. at the latter temperature.—S. K.

Use of Illinois Coal for Production of Metallurgical Coke. F. H. Reed, H. W. Jackman, O. W. Rees, G. R. Yohe, and P. W. Henline. (Illinois State Geological Survey, 1947, Bulletin 71: British Abstracts, BI., 1948, Aug., col. 370).

Production of a Metallurgical Coke from the Resin of Wallaba Wood (*Eperua* Sp.). R. H. Farmer and W. G. Campbell. (Journal of the Society of Chemical Industry, 1948, vol. 67, June, pp. 233–234). The wood of the wallaba tree of British Guiana contains a high proportion of an alcohol-soluble resin of a phenolic type. It is shown that this resin can be converted by controlled destructive distillation into a metallurgical coke of high purity and good physical properties. The volatile products of the distillation include a complex mixture of phenols which has useful fungicidal properties, and a combustible gas.

Carbonizing Properties of Coking Coals. R. E. Brewer, D. A. Reynolds, W. A. Steiner, and R. D. Van Gilder. (Industrial and Engineering Chemistry, 1948, vol. 40, July, pp. 1243–1254). The effect of oxidation of coking coal was studied by agglutinating and carbonization tests, and by chemical analyses on eleven coking coals after oxidation at room temperature, and at 99·3° C., and without oxidation. In general, continued oxidation decreased the agglutinating value, the carbon and hydrogen contents, and the calorific value, and it increased the real specific gravity and oxygen content. Oxidation also decreased the strength and fusion of the coke and the yield of tar, whilst it increased the yield of ammonium sulphate.—R. A. R.

The Free-Expansion Oven. (Coke and Gas, 1948, vol. 10, Aug., pp. 263–268). A description is given of the construction of a 'free-expansion' coke-oven invented by D. Petit. In this the oven walls are built of silica bricks on top of regenerator walls built of a refractory with small or zero expansion, such as semi-silica brick, the two being divided by a horizontal sliding joint. Four oven chambers 37 ft. 9 in. long have been built as an extension to an existing battery at Pont-à-Vendin and experience with them has been favourable. The silica brick walls are built in panels 41 in. long with suitable expansion gaps in between; the walls are supported by backstays and tie-rods in the usual way.—R. A. R.

Method of Determining the Change in Volume of Coking Material at High Temperatures. L. I. Erkin and L. I. Gorbunova. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 801–807). [In Russian]. An account is given of dilatometric experiments, carried out on cylindrical specimens of semi-coke produced from some Russian coals under standard conditions. The specimens were heated in an electrical tube furnace, their changes in length being transmitted to a dilatometer by a quartz rod. Rates of heating of 3°, 5° and 10°/min., respectively, were found to give contraction–temperature curves of the same shape, but with appreciably less contraction for the higher rates. The greatest speed of contraction was observed in the 750°–800° C. range, that at 1100° C. still being considerable. Contraction–time curves were also obtained for similar specimens under isothermal conditions at 700°, 900° and 1100° C., respectively, and the linear changes produced on heating coke to various temperatures up to 1200° C. were investigated.—S. K.

Lorraine Coking Coals. É. Laison. (Centre d'Études et Recherches des Charbonnages de France, 1947, Nov., Doc. 47-10: [Abstract] Monthly Bulletin of the British Coal Utilisation Research Association, 1948, vol. 12, June, p. 216).

A study of the coking properties of coals from the Lorraine basin. The best quality coking coal comes from the northern district of the Pas de Calais. Blending for metallurgical coke production is discussed.

The Recovery of Coke Oven Ammonia. P. J. Wilson and J. H. Wells. (Blast Furnace and Coke Association of the Chicago District: Blast Furnace and Steel Plant, 1948, vol. 36, July, pp. 806–812; Aug., pp. 961–964). The largest single item in the cost of recovery of ammonia from coke-oven gases is sulphuric acid. The author discusses four possible methods of eliminating this cost: (1) The substitution for the acid of a cheaper sulphate such as ferrous sulphate from pickle liquor, or calcium sulphate as natural gypsum; (2) the manufacture of a concentrated ammonia liquor or possibly anhydrous ammonia; (3) the recovery of hydrogen sulphide in a form suitable for conversion into acid; and (4) the manufacture of the ammonium salts with acid radicles available on the plant. It is concluded that though the adoption of these methods may be justified at certain plants, in the majority of cases the manufacture of ammonium sulphate is still the best method of disposing of ammonia.—J. P. S.

A Suggested Method for the Determination of Coke Reactivity to Carbon Dioxide at Combustion Temperatures. H. E. Flanders. (American Foundrymen's Association, 1948, Preprint No. 48-37). The generally poor operation of cupolas in recent years has been attributed to the improper preparation of coke for foundry use. In an effort to determine the fundamental differences between good and bad coke a method of determining the rate of reaction of coke to carbon dioxide at the temperatures existing in cupola combustion is proposed. It is based on the analysis of combustion gases, as a column of coke burns as nearly adiabatically as possible. From the relation of the composition to the height of the coke column the rate of the reaction can be approximately determined and the coke reactivity to carbon dioxide estimated as a function of temperature.

Calculating the Gasification Efficiency, when Gasifying Coke in Producers, from the Results of Gas Analyses. W. Mantel and E. Hülsbruch. (Glückauf, 1948, vol. 81–84, Sept. 25, pp. 656–660).

Recent Trends in Gas-Producer Practice. T. J. Brzozowski. (Monthly Bulletin of the British Coal Utilisation Research Association, 1948, vol. 12, July, pp. 237–244). The developments in gas-producer practice, including the Winkler and Kopper processes, and the I.C.I. fluidized gas generator, are reviewed. The bibliography contains 31 references.—R. F. F.

Clean Gas. E. H. Akers and P. Clarke. (ESC News, 1948, vol. 2, Autumn Issue, pp. 28–29). A brief description is given of the new Whessoe plant for cleaning producer gas at the Darlington works of the English Steel Corporation, Ltd. The cleaning is in four stages: (1) Primary cooling and partial detarring in a twin pass with washer; (2) first or hot-gas stage of electrostatic tar precipitation; (3) final cooling and washing in a ceramic-ring-filled tower; and (4) second stage electrostatic oil stripping.—R. A. R.

The Production of Long-Distance Gas from Austrian Coal at the Mine by the Lurgi Process and Its Advantages in Energy Economy. O. Rieger. (Industrie und Technik, 1948, vol. 3, No. 9, pp. 181–188).

Controls for Multiple Fuels. W. F. Pray. (Iron and Steel Engineer, 1948, vol. 25, Aug., pp. 61–66). The author deals with automatic control systems for the handling of multiple fuels and illustrates some control schemes for mixing, and one which provides fuel control in a complete steel plant with coke-oven gas as primary fuel, but is often supplemented by natural gas and air. Charts are also included showing the errors in air requirements and calorific values when natural gas and air are used as a substitute for various percentages of coke-oven gas, the error in calorific value when natural gas and air are substituted in a mixture with coke-oven gas using an orifice meter control, and the errors for various combinations of coke-oven gas, natural gas, and propane.—R. E.

Discussion on the Engineering Aspects of the Distribution and Utilization of Gaseous Fuels in Iron and Steel Works. (The Iron and Steel Engineers Group of The Iron and Steel Institute: Journal of The Iron and Steel Institute, 1948, vol. 160, Sept., pp. 85–94).

The Use of Fuel Oil in Furnaces for the Iron and Steel Fabricating Industries. M. Roddan. (Institute of Petroleum and Institute of Fuel, Joint Conference on Modern Applications of Liquid Fuel, Sept., 1948). The first part of the paper outlines the various factors which influence the overall efficiency of oil-fired furnaces; then follow descriptions of the normal types of burners used; finally, typical examples of oil-fired furnaces are described with details of the results obtained in practice.—R. A. R.

Fuel Oil in the Steel Industry in the U.S.A. A. J. Fisher. (Institute of Petroleum and Institute of Fuel, Joint Conference on Modern Applications of Liquid Fuels, Sept., 1948). After reviewing the estimated fuel reserves of the U.S.A. and the production and consumption of oil refining products, the use of fuel oils in all the phases of the steel industry is discussed, with data on furnace temperatures, oil consumption and the results obtained.—R. A. R.

TEMPERATURE MEASUREMENT AND CONTROL

Temperatures in the Open-Hearth Furnace. R. B. Sosman. (Howe Memorial Lecture: American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2435: Metals Technology, 1948, vol. 15, Aug.). In this survey of temperatures in the basic open-hearth furnace, the author refers particularly to temperatures in the bath and methods for their measurement, giving descriptions of different kinds of pyrometer. Special reference is made to the development of the Photronic (blowing tube) pyrometer and its calibration which enables the temperature of molten steel to be determined within an accuracy of 3° C., irrespective of the composition of the steel. Means of checking the precision of the instrument are considered and the results of new investigations on emissivity of liquid iron and steel are discussed. Other parts of this paper deal with pyrometry of the slag, roof, walls, bottom, regenerators, gases, and the flame. A list of 34 references is appended.—J. C. R.

Measurement of the Temperature of Liquid Steel Baths Using a Combined Thermoelectric Couple or by Other Methods. V. S. Kocho. (Zavodskaya Laboratoriya, 1946, vol. 12, No. 7–8, pp. 702–711) [in Russian].

Recommendations for a Simple Thermal Control for Cupola Operation. W. Callenberg. (Neue Giesserei, 1948, vol. 33–35, Aug., pp. 45–47). Equipment is described for measuring the flow and pressure of cupola blast and the flue-gas and casting temperatures, and for taking samples of flue gas.—R. A. R.

Vacuum Furnace Control. F. F. Davis. (Electronics, 1948, vol. 21, No. 5, p. 81: Metallurgical Abstracts, 1948, vol. 15, July, pp. 532–533). Davis describes a method of safeguarding the tungsten heaters against burn-out due to excessive gas pressure. Switching of the tungsten elements is automatically controlled by an electronic circuit in which a thermistor is used as the sensing element. The thermistor operates a calibrated indicator and a relay in the current circuits.

REFRACTORY MATERIALS

The New Modern Basic Refractories Plant of Harbison-Walker Refractories Company at Baltimore, Maryland. (Refractories Journal, 1948, vol. 24, Sept., pp. 324–339). An illustrated description is given of the new plant at Baltimore, where, by a high degree of mechanization and by closely controlling all operations, high quality refractory bricks are produced at up to 35,000 per day.—R. A. R.

Refractories Manufacturer Develops Precise Processes to Meet Steelmakers' Demands. C. Longenecker. (Blast Furnace and Steel Plant, 1948, vol. 36, Sept., pp. 1085–1088, 1094). The quarrying, sizing, and roasting plants of Basic Refractories, Inc., at Maple Grove, O., are described. The dolomite as quarried contains MgO 20·8%, CaO 30·8%, CO_2 47·5%, and SiO_2 0·5%. By crushing and screening, this is produced in a range of sizes suitable for blast-furnace and open-hearth use, for foundry fluxes, and for agricultural liming. It is ground to a $\frac{3}{8}$-in. to $\frac{1}{8}$-in. size when required for dead-burning in the kilns. In one plant it is mixed with iron oxide, roasted at 1650° C., and sold as "Magnefer" and "Syndolag" for fettling in open-hearths and electric furnaces, and in another it is mixed with brucite, a natural magnesium hydroxide, roasted and sold either as "Basifrit," quick-setting magnesia refractory or, when further ground and combined with chemical bonding agents, as "Ramset" and "Gunmix." J. P. S.

Manufacture and Use of Silica Bricks for Open-Hearth Furnace Roofs. E. Delaval. (Revue de Métallurgie, Mémoires,

1948, vol. 45, May–June, pp. 160–170). The manufacture of silica bricks from Belgian flint is described in detail and the results of the use of the bricks in the roof of an open-hearth furnace are recorded. The analysis of the raw material was: Loss on ignition, 0·55%; SiO_2, 96·40%; Al_2O_3, 0·41%; Fe_2O_3, 1·40%; CaO, 0·90%; MgO, 0·20%. That of the bricks was: Loss on ignition, 0·10%; SiO_2, 95·35%; Al_2O_3, 0·42%; Fe_2O_3, 2·40%; CaO 1·80%; TiO_2, 0·03%. Under the microscope the material was crystobalite with a few very small rods of nascent tridymite; the true specific gravity was 2·34. Following the detailed account of the brickmaking, the construction of the roof, the heating up of the furnace, and examinations of the roof and its bricks after service are discussed. After 462 heats the roof was still in usable condition. No brick had run; wear had taken place on a more or less horizontal plane, but was greatest above the taphole. Micro-examination showed that the inner face of the bricks was of stable crystobalite, behind which was a black zone of tridymite in large crystals, then a brown zone of small-grained tridymite, and finally the light unchanged zone of crystobalite and nascent tridymite.—A. E. C.

Use of Quartz Pelites in the Production of Dinas and Semi-Acid Refractories. V. A. Bron. (Ogneupory, 1947, vol. 12, pp. 113–123: American Ceramic Abstracts, 1948, vol. 31, Aug. 1, p. 179).

The Importance of the Sintering Medium in the Production of Magnesite Bricks. H. van Thiel. (Die Technik, 1947, vol. 2, July, pp. 319–321). The lack of natural magnesite in Germany has led to investigations of the possibilities of making magnesite bricks from precipitated magnesia. Laboratory tests are described in which certain waste materials containing SiO_2, Fe_2O_3, and Al_2O_3, which were available were tried as sintering agents for the precipitated magnesia.—R. A. R.

Power in Relation to Process Requirements in the Heavy Clay and Refractories Industries. E. Rowden. (Transactions of the British Ceramic Society, 1948, vol. 47, Sept., pp. 327–351). The efficiency of different types of fuel and plant used for power and drying purposes in the heavy clay and refractories industries are compared. The efficiency of power generation with condensing engines, compound back-pressure engines, and single-cylinder back-pressure engines is considered and improvements that could be obtained in works are suggested.—R. F. F.

The Qualities of Various Present-Day French Lining Materials Compared with Some Foreign Products. P. Nicolas. (Fonderie, 1948, Apr., pp. 1124–1132). French, Belgian and German refractory lining materials were subjected to the following tests: Physical analysis with measurement of binding strength: chemical analysis; measurement of refractoriness; and measurement of corrosion resistance. The results are briefly discussed.—J. C. R.

Refractory Materials for Lining Blast Furnaces. L. Pompei. (Metallurgia Italiana, 1947, vol. 39, Nov.–Dec., pp. 281–284). Chemical compositions, thermal and mechanical properties, and applications of various types of refractory materials are reviewed.

Testing Refractories for the Foundry. S. M. Swain. (American Foundrymen's Association, 1948, Preprint No. 48-26). The planning of a testing programme and the testing procedure for refractories used in foundries are discussed.—R. F. F.

The Behaviour of Firebricks on Reheating. J. F. Clements. (Transactions of the British Ceramic Society, 1948, vol. 47, Oct., pp. 379–396). Tests employing continuous measurement of the length changes occurring in the after-contraction test have shown that firebricks can be divided arbitrarily into four groups according to their behaviour is the test. These four groups contain: (1) Bricks which contract throughout the test; (2) bricks which contract until the testing temperature is reached and then remain constant in dimensions; (3) bricks which contract in the early stages of the test and afterwards expand: and (4) bricks which expand without first contracting. After-contraction tests carried out at a lower temperature will generally reveal the type of behaviour operating in a particular firebrick.

A study of the effect of grog content and firing temperature on fireclay mixtures has shown that the modes of behaviour described above result from the contending influence of firing shrinkage and expansion forces acting simultaneously. High firing temperature and small grog contents favour after-expansion, low firing temperature and high grog contents tend to produce after-contraction. Local variations in grog content or grading within individual bricks give rise to irregularities in reheat behaviour which make it impossible to obtain consistent after-contraction values from some types of firebricks. Examples of variability within individual bricks are illustrated and the importance of assessing the degree of variability of test material is stressed.

Organic Compounds of Silicon Refractories. A. E. L. Jervis. (Electrical Manufacturer, 1948, vol. 4, Mar., pp. 95–96 and 103: [Abstract] PERA Bulletin, 1948, vol. 1, June, p. 485). The article gives a brief description of the properties and application of zirconal refractories. Zirconal, a synthetic zircon, produced by high temperature chemical reaction between zirconia and silica, is particularly applicable to components which have to withstand intense heat, such as refractory nozzles, but potential applications include blades, nozzles, etc., for gas turbines, linings for electric and other furnaces, low-loss containers for high-frequency heating units, bearings, and sand-blast nozzles. The properties and characteristics of the two grades, Zirconal "N" and Zirconal "X" are described.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Potentialities of the Pressure Blast Furnace. B. S. Old and E. R. Poor. (Mining and Metallurgy, 1948, vol. 29, July, pp. 385–387). Experiments carried out by the Republic Steel Corporation indicate that pressure blowing is a solution to the problem of increasing pig-iron capacity without necessitating major changes in existing equipment. Iron production has been increased 11% to 20% per day with a decrease of 13% in coke rate per ton of pig iron and a 30% reduction in flue-dust production.—R. E.

Effect of Coke Quality on Blast Furnace Iron Tonnage. E. J. Gardner. (Steel, 1948, vol. 123, Oct. 4, pp. 94–98, 116, 119). *See* Journ. I. and S.I., 1948, vol. 160, Sept., pp. 101–102).

Dephosphorizing and Desulphurizing Pig Iron. G. Grenier. (Echo des Mines, 1948, Aug., pp. 156–157; Sept. pp. 177–178). Dephosphorizing and desulphurizing pig iron are discussed. R. F. F.

Cupolas for Producing Synthetic Pig Iron. H. Reininger. (Die Technik, 1947, vol. 2, July, p. 337). Cupola practice for melting down scrap from bomb-damaged buildings is discussed with an example of the use in the United States of a water-cooled cupola for 120-hr. campaigns.—R. A. R.

Application of Electric Low-Frequency Induction Furnace for Iron Smelting. H. A. Werneck. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Jan., pp. 5–28: [Abstract] Metals Review, 1948, vol. 21, July, p. 6). The application of the electric low-frequency induction furnace for iron smelting is studied with particular respect to Brazilian conditions and to three principal factors: Energy consumption, cost of production, and a duplex method using a cupola furnace in combination with a low-frequency induction furnace.

TREATMENT AND USE OF SLAGS

Changes in Slag Sands (Cement Slags) by Heating at 850°. F. Keil. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 7–9). The effect of heating granulated blast-furnace slag at 850° C. on its grinding and hydraulic properties was investigated. The hydraulicity may be reduced by one-third by the heating, but its grindability is very greatly increased. The sulphide in it is partly converted to sulphate, and the greater the amount converted the easier it is to grind.—R. A. R.

The Recovery of Vanadium from Slags which Arise in Steel Production. G. Trömel and H. Gedschold. (Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 119–124). Results obtained with full-scale plant in the recovery of vanadium from steel-making slags are reviewed and the results of laboratory tests to establish the optimum conditions for producing pure vanadium are reported. X-ray and microscopical studies of the constitution of these slags have been made: these established that the vanadium was present mainly as a manganese-bearing spinel.—R. A. R.

The Manufacture of Mineral Wool. J. E. Gillespie. (Canadian Mining and Metallurgical Bulletin, 1948, vol. 41, Jan., pp. 20–24). The manufacture of mineral wood is described. A cupola producing 36 tons of semi-rigid mineral wool per day would consume 36¼ tons of slag, 8 tons of coke, 550 gallons

of fuel oil for curing the binder, and 22,000 lb. of steam for fibre production, and about 12 men per shift would be required to operate the plant.—R. A. R.

PRODUCTION OF STEEL

British Iron and Steel Research Association. (Metallurgia, 1948, vol. 38, Sept., pp. 270–272). Brief accounts are given of the work in progress, and its purpose, by the Steel Castings, Ironmaking, Steelmaking, Mechanical Working, Plant Engineering, and Metallurgy Divisions of the British Iron and Steel Research Association.

Future Scrap Sources for the Steel Plants. C. H. Holton. (Steel, 1948, vol. 123, Sept. 13, pp. 128–135, 138–146). **Future Sources of Iron Units in Scrap.** C. R. Holton. (Yearbook of the American Iron and Steel Institute, 1948, pp. 346–367). *See* Journ. I. and S.I., 1948, vol. 160, Sept., p. 103.

French Steel Capacity. Considerable Programme of Modernization. S. H. Kahn. (Iron and Steel, 1948, vol. 21, Aug., p. 362). A statistical account of the present position of the French iron and steel industry is given, with brief notes on future development plans.—J. C. R.

Economic Advantages Offered by Side Blow Converters. A. W. Gregg. (Steel, 1948, vol. 123, Aug. 23, pp. 98–104). The side-blown converter offers advantages in the production of steel, both for foundries and for mills, and is superior to the bottom-blown converter in many ways. The blowing equipment is less costly, as a lower pressure is required. The use of oxygen should be investigated.—J. P. S.

Oxygen in Side Blown Converters. M. E. Davies. (Iron Age, 1948, vol. 162, Sept. 2, pp. 87–91). The experiments carried out by the British Iron and Steel Research Association in conjunction with Messrs. Catton and Co., Leeds, are described. These extensive trials suggest the following advantages: (1) shorter blowing time and great flexibility, (2) higher steel temperature, (3) reduction in silicon and fuel consumption, (4) more consistent composition of steel, and (5) conversion of the converter from a scrap producer to a scrap consumer. The cost of oxygen is the outstanding disadvantage, but this may be overcome if a larger scale of working is adopted.

J. P. S.

Steel Making—The Acid Open-Hearth Process. W. H. Stratford. (ESG News, 1948, vol. 2, Autumn Issue, pp. 2–9) An illustrated description is given of the acid open-hearth process of steelmaking.—R. A. R.

Influence of Sulphur in the Fuel Gas on Sulphur-Removal in the Basic Open-Hearth Furnace. C. W. Short and T. G. Meyrick. (Iron and Coal Trades Review, 1948, vol. 157, Oct. 1, pp. 725–727). Investigations have been carried out by the authors into the influence of moderate amounts of sulphur in the fuel gas on sulphur removal in the basic open-hearth furnace. Extensive trials at Normanby Park Steel Works of John Lysaght's Scunthorpe Works Ltd., disclosed that although the use of sulphur-free gas is somewhat advantageous as revealed by average results, none of the differences was significant. Moreover, from the widely varying values of individual charges throughout the trials, it was clear that factors other than the sulphur content of the fuel gas exert a dominating effect on the behaviour of that element.

Open Hearth Fume Control. E. S. Kopecki. (Iron Age, 1948, vol. 162, Sept. 9, pp. 78–80). The use of the oxygen lance increases the problem of the emission of smoke and fumes from the open-hearth stack. The Republic Steel Corp. has designed and installed a venturi scrubber. Low-velocity water is injected through jets into the dirty gas stream, in its direction of flow, just before the throat of the venturi; the gas accelerates and disrupts the jets, and the mixture of gas and spray is then decelerated and separated. Up to 1000 lb. of dust per heat are removed.—J. P. S.

Oil-Fired Open Hearth Furnaces—A Review of British Practice. T. C. Bailey. (Institute of Petroleum and Institute of Fuel, Joint Conference on Modern Applications of Liquid Fuels, Sept., 1948). An examination is made of what has been, and is being, done from the reception of the oil onwards, with a view to: (*a*) Deciding what can be considered as sound standard practice, (*b*) seeing where improvements are necessary, and (*c*) suggesting probable lines of development. The author considers that the best performance of a gas-fired furnace can be beaten by an oil-fired furnace where the closest attention is paid to burners, furnace design, charging facilities, and air control.—R. A. R.

Open-Hearth Furnace Instrumentation. E. Rogers. (Journal of The Iron and Steel Institute, 1948, vol. 160, Sept., pp. 57–72). A consideration of the difficulties of this subject leads to the statement of requirements for different classes of furnace operation. The variables of the open-hearth process are studied with the aid of a diagram showing inter-relationship. It is then decided which variables should be measured under the classes previously stated. Consideration of methods of measurement and presentation gives a plan for instrumentation of open-hearth furnaces in general.

First Report of the Open-Hearth Instruments Sub-Committee. F. L. Robertson. (Journal of The Iron and Steel Institute, 1948, vol 160, Sept., pp. 72–74). This report of the Open-Hearth Instruments Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association deals with the necessity for measuring instruments for open-hearth furnaces. Both managerial and technical necessities are stressed. Individual instruments are not treated in detail. The development of instrument usage is outlined, and instrument installation, maintenance, and inspection are discussed.

R. A. R.

Operation of Oxygen-Enriched Open-Hearth Furnaces. J. S. Marsh. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2416; Metals Technology, 1948, vol. 15, Aug.). Details are given of tests undertaken to examine the effect of oxygen-enrichment on open-hearth furnace operation. Heats with and without oxygen were alternated so that the effect of enrichment could be evaluated. Furnaces charges ranged from all-cold metal to 60% hot metal in the total metallic charge. Maximum rate of production resulted with enrichment to about 27% oxygen, and, on supervised tests, production increases ranged from 20% to 50% with fuel saving of 10–25%. It is pointed out, however, that the overall rate of routine production would probably be less than that indicated by special tests.

J. C. R.

Russian Steel-Making Research; Recent Work on Air-Oxygen Mixtures. (Chemical Age, 1948, vol. 58, June 5, pp. 785–786).

Oxygen in Steel. A. Antonioli. (Metallurgia Italiana, 1947, vol. 39, Nov.–Dec., pp. 289–293). A critical review is presented of the work of various investigators on oxygen equilibria in steel and methods for its determination.

Tonnage Oxygen, Versatile Aid for Increasing Iron and Steel Output. J. H. Strassburger. (American Iron and Steel Institute: Steel, 1948, vol. 123, Oct. 18, pp. 146–163). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 220.

Water-Cooled Cupola Features Duplexing Plant. E. S. Kopecki. (Iron Age, 1948, vol. 162, Aug. 19, pp. 81–85). The Central Iron and Steel Co., Harrisburg, Pa., employs three water-cooled cupolas for the production of hot metal for charging open-hearth furnaces. A mixture of steel scrap and cast iron scrap is employed in a 2 : 1 ratio which it is hoped to increase. By the use of water-cooling and special refractories, including a 3-in. layer of rammed carbon paste on the hearth bottom, it is hoped to attain a minimum of six months' run before patching is required.—J. P. S.

Single Slag Basic Electric Furnace Practice. W. R. Patterson and J. T. Evans. (Iron Age, 1948, vol. 162, Sept. 23, pp. 55–59). The chemical processes involved, and the practical steps entailed in producing a plain carbon steel under a single slag in the basic electric furnace are described.—J. P. S.

Application of a Single Slag Process to Basic Electric Steel. M. V. Healey and R. W. Thomas. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 368–374). The single-slag process is capable of producing a basic electric steel approaching the quality of basic open-hearth steel especially as regards grain-growth characteristics. Other advantages of the single-slag over the double-slag process for electric steelmaking are discussed, together with some operating requirements for the former.—R. F. F.

Device for Obtaining Samples of Slag at Varying Depths from Open Hearth Furnaces. M. Y. Medshibozhsky. (Zavodskaya Laboratoriya, 1948, vol. 14, No. 1, pp. 113–115: [Abstract] Engineers' Digest (London), 1948, vol. 9, Aug., p. 284). The usual method of testing the composition of slag by taking a sample with a ladle is not considered satisfactory as the results obtained are only applicable to the level or depth at which the sample is extracted. It is well known, however, that the composition of slag varies with

the level at which the sample is obtained. The device described in the article permits of obtaining several samples simultaneously at different levels in the open-hearth furnace. It consists of several mild steel pans which are attached to a common spindle. The distance between pans can be varied by threading loose sleeves over the spindle between the pans. The whole structure is held together by the two end nuts and can be manipulated by means of a handle. The device is introduced into the hearth in a horizontal position and is then placed upright. To prevent the slag from entering the pans near the top, these are covered with a thin copper foil which subsequently melts with the heat of the slag, permitting the latter to fill the pans simultaneously at different levels and to solidify. The device is withdrawn after 6 to 7 sec.—the time required to melt a copper foil of 0·25-mm. thickness. During withdrawal, slag from the top level collects on top of the pans and this is consequently removed, leaving the pans filled to two-thirds of their depth. The pans can be easily removed and their number may be varied in accordance with the depth of slag in the hearth. Copper is selected for the foil because it is not easily subject to oxidization and, therefore, does not influence the composition of the slag samples. The device can be further improved by tying washers on copper wire above the pans. When the copper wire melts, the washers fall on top of the pans, thus ensuring that the slag is only collected at the desired levels. Tests carried out with this device yielded remarkable results and proved that slag is not homogeneous throughout its depth. The variation of slag composition is found to follow certain laws; for instance, it is invariably found that the iron oxide (Fe_2O_3) content of slag drops from top to bottom, whereas the content of FeO increases as the depth increases.

Slag Control in the Acid Electric Furnace. H. H. Johnson, M. T. McDonough, and D. L. Radford. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 520–532). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 292.

Continuous Casting of Semifinished Steel. T. W. Lippert. (Iron Age, 1948, vol. 162, Aug. 19, pp. 72–80, 159–161). The history and the advantages of the continuous casting of steel are dealt with at length and a brief description is given of the new plant jointly operated by Republic Steel Corporation and Babcock and Wilcox Tube Company at Beaver Falls, Pa., under the patents of the Williams process. Steel in cross-sections of about 30 sq. in. usually in 6-in. rounds is cast at 400 lb./min. The apparatus is installed vertically in a 75-ft. tower; molten steel, brought from electric furnaces in a transfer ladle is poured through a tundish which removes slag into a vertical water-cooled mould. The chilled billet is drawn through pinch rolls and cut automatically to length.—J. P. S.

The Heat Equilibrium between Ingot and Ingot-Mould Wall. B. Matuschka. (Iron and Steel Institute, 1948, Translation Series, No. 359). This is an English translation of a paper which appeared in Archiv für das Eisenhüttenwesen, 1929, vol. 2, June, pp. 405–413 (*see* Journ. I. and S.I., 1929, No. I, p. 714).—R. A. R.

The Origin of Silicate Inclusions in Basic Electric-Arc-Furnace Steel of Higher Carbon Contents. A. Hultgren. (American Institute of Mining and Metallurgical Engineers, Technical Publication, No. 2418: Metals Technology, 1948, vol. 15, Aug.). *See* Journ. I. and S.I., 1946, No. I, p. 42A, *and* 1947, vol. 157, Dec., p. 633.

FOUNDRY PRACTICE

Adaptation of the Principle of Automatic Cupola Charging to an Existing Installation. R. Lesage. (Fonderie, 1947, June, pp. 694–696). A detailed and illustrated plan is outlined for an installation with two cupolas where it is intended to adopt automatic charging.—J. C. R.

Melting in the Cupola with Very Poor Quality Coke. H. Gernelle. (Fonderie, 1947, May, pp. 658–663). After outlining the difficulties that arise in cupola practice when the coke used is too porous or has a high ash content, the author discusses modifications that may be made in the cupola itself, *e.g.*, rectangular instead of round tuyeres and the introduction of a fore-hearth, or in its operation where very poor quality coke has to be used.—J. C. R.

Foundry Melting Coke—An Old and Always Present Problem. J. H. Küster. (Neue Giesserei, 1948, vol. 33–35, July, pp. 6–8). Changes in the quality of German foundry coke are reviewed and some of the measures for improving production at German foundries now using coke of poor quality are described.—R. A. R.

Calculation of the Charge. G. Joly. (Fonderie, 1947, Feb., pp. 539–541). A short practical note is presented on the calculation of the charge when refining hematite, phosphoric iron, and scrap of known composition to obtain cast irons of specified compositions.—J. C. R.

New Concepts Regarding Cupola Melting Operations. A. Kentischer. (Neue Giesserei, 1948, vol. 33–35, Sept., pp. 75–80). It is shown that carburization in the cupola takes place almost entirely above the combustion zone. With good driving the melting zone is in the reducing zone above where combustion takes place. Carburization and superheating are dependent on the height of the reducing zone, and this height fluctuates markedly because of the charging and other conditions. These fluctuations can be limited by rapidly moving the combustion zone by alternately putting in and cutting out different rows of tuyeres. This technique prevents marked fluctuations in carburization. As the desired small degree of carburization limits the formation of carbon monoxide it is not permissible to have any excess of carbon monoxide and the coke consumption is consequently reduced to a minimum, *i.e.*, to 10–11% for low carbon malleable iron, and 9–10% for high quality cast iron.—R. A. R.

German Foundry Practice—Interrogation of Dr. Lanzendorfer. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1802: H.M. Stationery Office). A report, based on information supplied by Dr. Lanzendorfer of Deutsche Eisenwerke, Mulheim, is presented with descriptions of German foundry practice using cupolas, side-blown converters, and the electric-arc furnace. His comments on British foundry practice are also given.—R. A. R.

Dimensions and Shapes of Cupola Tuyeres. G. Joly. (Fonderie 1947, May, pp. 651–654). After noting the importance of the relationship between the total area of the tuyeres and the area of an inside section of the cupola when considering speed of air flow through the tuyeres, the author shows how these areas are related to coke consumption. He also discusses the number, shape, and position of the tuyeres which are likely to result in an even distribution of the air flow inside the cupola, regular operation of the cupola, minimum wear of the lining, and no oxidation of the metal.—J. C. R.

Addition of Chromium and Nickel to Iron. G. Joly. (Fonderie, 1947, Jan., p. 497). Brief notes are given on methods of adding chromium and nickel to iron either in the ladle or in the cupola.—J. C. R.

Production by the Cupola Process of Hardened Cast-Iron Rolling-Mill Rolls. H. Dubois and G. Hénon. (Fonderie, 1947, Sept., pp. 787–797). An account is given of processes involved in the manufacture of rolling-mill rolls. Reference is made to the mould and especially to the chills, the properties required by the rolls, their hardness, and depth of hardness. A description of the make-up of the charge, the melting and casting processes is given. Finally the causes of defects in rolls are analysed.—J. C. R.

The Utilization of Iron Turnings in a Rotary Furnace. H. Gernelle. (Fonderie, 1947, Aug., pp. 772–775). High-strength cast irons made in an oil-fired rotary furnace from iron turnings were found to contain blowholes. To remedy this defect melting took place more rapidly in an oxidizing or neutral atmosphere. Reference is made to other factors, such as the composition of the charge, control of the flame, nature of the slag and recarburization, which affect the final product. The suggested charge is 70% iron turnings, 20% ingot croppings, and 10% malleable hematite iron. While the cast iron obtained does not possess very good machining qualities, it will have very good mechanical properties having regard to the phosphorus content.—J. C. R.

Modern Technique in the Production of Black-Heart Malleable Iron in the Cupola in Czechoslovakia. M. Knotek. (Fonderie, 1947, Dec., pp. 961–962). A summary is given of a paper in which the author describes the practice at two works in Czechoslovakia producing blackheart malleable iron using 40% steel scrap.—J. C. R.

Effect of Manganese-Sulphur Ratio on the Rate of Anneal of Black-Heart Malleable Iron. J. E. Rehder. (American Foundrymen's Association, 1948, Preprint No. 48-30). In order to find the ratio of manganese to sulphur in white cast iron suitable for making blackheart malleable iron, which will give minimum annealing time, two series of test

bars were cast in which the manganese content was varied. One series contained 0·09% and the other 0·21% of sulphur, other constituents being in normal amounts used in commercial malleable foundries. Minimum first and second-stage isothermal annealing times were determined for each bar, and the results plotted against manganese/sulphur ratio. It is shown that pronounced minima are produced in second-stage (sub-critical) annealing times by a suitable manganese/sulphur ratio, with less effect on first-stage annealing times. With higher sulphur content the minimum is in a narrower range of manganese than with low sulphur content, indicating that better control of the manganese is important commercially in high-sulphur white irons. The optimum manganese content is given by the formula $Mn(\%) = (1{\cdot}7 \times \%S) + 0{\cdot}15$.

The Production of Low Carbon Malleable Iron in the Converter. H. Triebeler. (Neue Giesserei, 1948, vol. 33–35, Oct., pp. 122–123). The development in different countries of duplex processes, in which the second stage is blowing in a converter, for producing low carbon malleable iron is reviewed.—R. A. R.

Construction and Operation of an Oil-Fired Malleable Iron Holding Furnace. F. Coghlin, jun. (American Foundrymen's Association, 1948, Preprint No. 48-18). The design and construction of an oil-fired holding furnace, used for malleable iron duplexing, is described. The operating conditions and fuel and refractory consumptions of this furnace are discussed. R. F. F.

Changes in Chemistry of Liquid Steel in Contact with Sand. (American Foundrymen's Association, 1948, Preprint No. 48-29). The Mold Surface Committee of the American Foundrymen's Association presents a study and report on phenomena at the sand-metal interface when a mould surface is subjected to liquid metal. One of the many phenomena is a change in the chemical compositions of the sand and metal. This report is concerned with changes in the composition of the metal (the instances reported are for steel) when it contacts the sand to form the casting. A corollary of this work has to do with any possible oxidation or volatilization of steel as an explanation of penetration and adhering sand.

High-Frequency Furnaces in the Steel Foundry. D. K. Barclay. (Journal of Scientific and Industrial Research (India), 1947, vol. 6, Series A, pp. 372–374 : British Abstracts, 1948, BI, Aug., col. 408). The construction and operation of these furnaces are briefly described.

Evolution of Chilled Wheel Rims. (Railway Age, 1948, vol. 124, June 26, pp. 86–87 : Railway Engineering Abstracts, 1948, vol. 3, Sept., p. 243). A notable improvement in wheel safety has resulted from advancements in chill control, wheel design, manufacturing processes, and testing methods in America, this being shown by the increased resistance to impact blows on the outer portion of the rim. This article describes the methods by which these improvements have been obtained and also gives particulars of an experimental design of chilled car wheel known as the A.AR.X-I wheel which aims at redistribution of metal for the purpose of increasing rim and flange strength. Metal has been removed from the hub and added to the tread section where stresses are comparatively high as compared with stresses at the hub. A photograph of the design is given.

Foundry Sand Laboratory. O. J. Myers. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 490–492). The purpose of a foundry-sand laboratory, the staff and equipment required, and methods of procedure are discussed.—R. F. F.

Granulometric Study of Foundry Sands. P. Nicolas. (Fonderie, 1947, Apr., pp. 629–630). A brief note is presented on the determination of the American Foundrymen's Association grain fineness number by the normal A.F.A. method using eleven sieves and by a method using a G.F. (Georges Fischer) apparatus with seven German standard sieves which gives a result approximately the same as the true A.F.A. grain fineness number.—J. C. R.

Particle Size Classification Scheme. P. Dauxois. (Fonderie, 1947, Dec., pp. 939–941). From a distribution curve plotted with a logarithmic scale for particle size and a linear scale for the percentage of the sand not passing a screen of given mesh, the coefficients of distribution, partition, and skewness are determined. From the two former, the screen sizes among which sand falling between two more widely separated sizes will distribute itself can be calculated, from the last two and the mean grain-size the whole distribution curve can be reconstituted, and the skew coefficient taken with the mean size indicates the amount of displacement of the distribution curve towards the coarse or the fine end of the scale.

Moreover, the use of these coefficients enables comparisons to be made between materials of different degrees of fineness. J. P. S.

Foundry Sand Reclamation. J. M. Cummings and W. M. Armstrong. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, July, pp. 24–26, 39, 40). An account is given of investigations by the British Columbia Research Council with a view to finding an economic method of reclaiming steelfoundry sand having regard to the fact that there are no suitable natural sands available in British Colombia and that not more than 4000 or 5000 tons/annum of sand are consumed in the Province. The design of a plant costing less than $10,000 is outlined.—R. A. R.

Sand Replaces Loam as Moulding Material in the Foundry. K. Stock. (Neue Giesserei, 1948, vol. 33–35, Sept., pp. 74–75). The advantages and disadvantages of clay-free silica sand and clay-bearing sand as a moulding material are discussed with notes on cement-sand moulding.—R. A. R.

Search for New Foundry Sands in the Marseilles Area. P. Nicolas. (Fonderie, 1947, Mar., pp. 582–591). After outlining the composition and properties of foundry sands from the Marseilles area which are at present in use, the author gives brief notes on sixteen foundry sands taken from the same area.—J. C. R.

Technique and Development of Foundry Facing Materials. P. Nicolas. (Fonderie, 1947, Oct., pp. 843–852). An account is given of the chemical characteristics of some French, British, American, Belgian, and German facing materials used to coat mould and core surfaces, or mixed into the moulding sands.—J. C. R.

The Compressibility of Moulding Sand. K. Roesch. (Neue Giesserei, 1948, vol. 33–35, July, pp. 11–13). The relationship between the compressibility and the permeability of moulding sands is considered, and it is recommended that compressibility be determined by the reduction in permeability after 3, 6, and 12 blows with the rammer.—R. A. R.

Thermal Conductivity of a Sand Mixture. C. F. Lucks, O. L. Linebrink and K. L. Johnson. (American Foundrymen's Association, 1948, Preprint No. 48-17, pp. 1–4). The authors have determined the thermal conductivity of a sand mixture over a temperature range of 750° to 2250° F. In an appendix J. C. Bell presents the results of a study of the thermal conductivity of dry sands.—R. E.

The Sand-Preparation Shop in Foundry Mechanization. H. Perchat. (Fonderie, 1947, Dec., pp. 925–927). A brief account is given of ways in which mechanization can be introduced into the sand-preparation shop.—J. C. R.

Chemically Treated Sand. Process for the Preparation of a Foundry Sand Using a Resin Binder. T. W. Curry. (Fonderie, 1947, Dec., pp. 934–938). The author examines a process of coating grains of foundry sand with a viscous liquid containing a carbon-rich resin, a solvent, and water, which packed the sand tighter and gave a more uniform hardness than other synthetic sands. The method of treating the sand is described and an account is given of its performance in practice. It is claimed that castings have a better finish, that stripping is facilitated, and that the knock-out sand is of good quality for re-use.—J. C. R.

Use of Synthetic Sand for Cast Magnets. R. S. Turner. (Foundry Trade Journal, 1948, vol. 85, Aug. 12, pp. 153–154). An account is presented of experiments carried out to reduce the cost of facing sand, to obtain a smoother finish on castings, and to find a sand suitable for some very small magnets, when manufacturing large quantities of small cast permanent magnets. Results show that satisfactory magnets could be made using a clay-bonded instead of an oil-bonded sand, and surface finish was often better.—J. C. R.

Core-Moulds for Stainless Steel Castings. R. S. Turner. (Foundry Trade Journal, 1948, vol. 85, Sept. 2, pp. 231–232). A method is outlined for making small stainless steel castings in fairly large numbers, using core moulds instead of the normal moulding boxes. The building of the core box and the assembly of the cores are described.—J. C. R.

Charcoal as an Addition to Moulding Sand. T. Kitice. (Boletim da Associacão Brasileira de Metais, 1948, vol. 4, Jan., pp. 94–98 : [Abstract] Metals Review, 1948, vol. 21,

July, p. 28). Results are presented of an investigation for the purpose of cost reduction. Photomicrographs show the structure of cores made in this way.

Improvement of the Physical Properties of Bentonite of Czech Origin by Chemical Treatment. J. Jarka. (Hutnické Listy, 1948, vol. 3, No. 7, pp. 201–203). [In Czech]. Chemical analysis and a series of experiments revealed, that by adding 5·3% of Na_2CO_3 the properties of Czech bentonite can be considerably improved and although the obtained product is not as good as the Black Hills bentonite, it compares favourably with the French and German bentonites.—E. G.

New Method for the Production of Bentonite. A. Bichler. (Hutnické Listy, 1948, vol. 3, No. 7, pp. 203–204). [In Czech]. A new method of producing synthetic bentonite has been developed which is based on the co-operative effect of ions within a certain range of cation contents. This co-operative effect occurs only over a certain range of ion contents, whilst outside this range the ions lose to a certain extent the properties which are responsible for the swelling capacity of the bentonite. This method is cheaper and more effective than the German method now used in Czechoslovakia.—E. G.

Practical Experience with Synthetic Moulding Sands with Bentonite in the United States of America. K. Endell. (Neue Giesserei, 1948, vol. 33–35, Aug., pp. 35–39).

Method of Investigation of the Process of Core Drying. H. H. Fairfield and C. D. Brosch. (Boletim da Associacão Brasileira de Metais, 1948, vol. 4, Jan., pp. 67–73 : [Abstract] Metals Review, 1948, vol. 21, July, p. 28). The use is described of a time–temperature diagram for graphic analysis of the process. Such a diagram is considered to be of value for industrial control.

Practical Methods for the Choice of Core Sand Binder for the Large Scale Production of Small Castings. G. Barrallon. (Fonderie, 1947, Nov., pp. 883–887). The author discusses the factors that govern the choice of a binding agent with reference to the green strength of the core and its behaviour during and after baking. During baking the core should not distort and the sand should be evenly distributed in the binder. After baking, the cores should possess sufficient strength to be handled without deterioration, should absorb the minimum amount of moisture to permit storage, and should generate the minimum of gas during casting operations. J. C. R.

A New Permeable Metal Casting Plaster. K. A. Miericke and E. S. Johnson. (American Foundrymen's Association, 1948, Preprint No. 48-20). A new material has been developed for precision casting with plaster moulds; it is based on gypsum and contains refractories, fibrous binders, and ingredients to provide a porous structure. Among its advantages are high permeability, a smooth finish, and a degree of heat insulation which permits the use of smaller gates and risers as well as a lower casting temperature.—J. P. S.

Core Box Designing and Rigging for Core Blowing. H. J. Jacobson. (American Foundrymen's Association, 1948, Preprint No. 48-56). This paper discusses three types of core boxes and two types of core blowing machine now in use. The author considers the suitability of various materials for use in core boxes and the design and rigging of core boxes to the core blowing machine.

Core Baking. (Automobile Engineer, 1948, vol. 38, Aug., p. 314). A brief description is given of the M-800A Thermonic electronic tunnel for baking cores which pass through it on a moving belt. The unit is 4 ft. 4 in. wide, 6 ft. 8 in. high, and 16 ft. 9 in. long. The heating time varies from 20 sec. to a few minutes.—R. A. R.

Large Conveyorized Core Ovens Feature Ford Foundry Rehabilitation Program. (Industrial Heating, 1948, vol. 15, Apr., pp. 647–658; May, pp. 829–834). Large horizontal and vertical core-drying ovens at a foundry of the Ford Motor Co. are described.—R. A. R.

Pattern Purchase Considerations. W. G. Schuller. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 204–207). *See* Journ. I. and S. I., 1947, vol. 157, Sept., p. 144.

Liquid Phenolic Casting Resins for Foundry Patterns. C. R. Simmons. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 516–519). *See* Journ. I. and S.I., 1948, vol. 158, Feb., p. 268.

Gating Practice—More Important Than Ever. H. Reininger. (Neue Giesserei, 1948, vol. 33–35, July, pp. 20–24). The recommendations of the Committee on Gating Practice of the Verein Deutscher Giessereifachleute, set up in 1944, are presented and discussed.—R. A. R.

Gating Practice and Its Effect on Yield, Casting Quality, Expenditure on Circulating Material, Production Costs and Rejects. J. Hagen. (Neue Giesserei, 1948, vol. 33–35, Aug., pp. 42–44). Four methods of gating for casting cylinder liners weighing about 36 lb. are described with data on the proportion of metal used in the gates, runners, and risers. The best method was downhill casting into a sprue with four radially distributed downgates. The 'LAT' (Lehmann-schen Anschnittechnik) procedure for determining the number and size of gates is described.—R. A. R.

A Theoretical Approach to the Problem of Dimensioning Risers. J. B. Caine. (American Foundrymen's Association, 1948, Preprint No. 48-36). A mathematical theory for the calculation of the minimum size of risers is suggested. This theory has been checked experimentally for steel and is based on heat evolved, heat dissipated, and volume contraction.—R. F. F.

Feeding of Metal Castings. A. F. Faber, jun., and D. T. Doll. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 461–475). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 292.

Calculating Sizes of Gates and Risers. N. Janco. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 296–300). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 292.

Temperature Distribution in Metal Molds. M. C. Udy and H. D. McIntire. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 208–220). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 293.

Knocking-Out Operations. P. Rigaut. (Fonderie, 1947, Dec., pp. 928–930). This paper outlines the methods used to break-up the mould after use and the procedure in hand-operated and mechanized knock-out shops.—J. C. R.

Chill Casting of Grey Iron. G. Joly (Fonderie, 1947, Apr., pp. 625–628). A description is given of the production of chilled grey iron castings and the merits and demerits of this process are summarized.—J. C. R.

The Use of Eccentric Strickles in the Moulding of Circular Castings in Segments where Machining is Required in Assembly. J. Pascal. (Fonderie, 1947, Dec., pp. 944–946). Circular objects, such as alternator end-frames or other heavy castings, are sometimes required to be made in a number of segments which are subsequently machined to fit into a perfect circle. The segments may be cast detached from each other, but in the same circular mould at the same time, if eccentric strickles are used to sweep out the mould, the axis of rotation of the strickle being displaced by one of a number of means so that each segment is swept from a separate centre, but has the radii required on the final assembled casting as well as the machining allowances necessary on the radial faces at the ends of the segments.—J. P. S.

Manufacture of a Crucible in Special Cast Iron for Precious Metals. P. Simon. (Fonderie, 1947, July, pp. 731–734). A description is given of the design, composition, and casting of a crucible for the treatment of precious metals.—J. C. R.

The Production of Steelworks' Ingot Moulds. A. Charmeau. (Fonderie, 1947, Apr., pp. 601–611). The author first analyses the properties required in an ingot mould. Special attention should be paid to such factors as uniform thickness of the mould to ensure even cooling of the ingot and avoid abnormal stresses, the internal dimensions of the mould and the inclination of the walls to the vertical, and smooth surface of the walls to facilitate stripping the ingot. The causes of ingot mould failure due to disintegration of the inside walls or the formation of cracks are discussed. A description is given of the method of producing ingot moulds at the Henri Paul Schneider foundry. Finally, consideration is given to the influence of various factors on the service life of ingot moulds.—J. C. R.

Processes for the Elimination of Defects in the Casting of a Worm Shaft. P. Simon and G. Joly. (Fonderie, 1947, May, pp. 655–657). A detailed and illustrated account is given of the processes involved in the preparation of the mould and the casting of a worm shaft.—J. C. R.

Precision Casting. E. D'Amico. (Metallurgia Italiana, 1947, vol. 39, Nov.–Dec., pp. 247–260). Modern methods and applications of precision casting are described.

Pressure Casting with Plastic Patterns. H. Chase. (Iron Age, 1948, vol. 162, Oct. 7, pp. 88–94). A cheap plastic material is used instead of wax in a mechanized precision casting plant using the 'lost wax' process; it consists of a mixture of two refractory flours with three binding solutions and water.—J. P. S.

Permanent Mold Castings—Ferrous and Nonferrous. H. Chase. (Materials and Methods, 1948, vol. 28, July, pp. 75–86). A comprehensive account is given of the gravity die-casting process. It covers the advantages and disadvantages of the process, the equipment and technique, selection of material for the mould, dimensional tolerances, and rules for designing castings to be made by this method.—R. A. R.

Foundry Methods Improve Investment Castings. K. R. Geist. (Machinist, 1948, vol. 92, Sept. 11, pp. 655–658). Improvements in precision investment casting technique used at the Allis-Chalmers' West Allis Works are described. These improvements include special machines for injecting wax, the adoption of foundry techniques and the use of induction melting furnaces with a capacity of 35 lb.—R. F. F.

The Present Position of Centrifugal Casting. J. Boucher. (Fonderie, 1947, Mar., pp. 553–563). Developments and modern practice in horizontal, inclined or vertical centrifugal casting, semi-centrifugal casting, and casting under centrifugal pressure are outlined. The machines used are described and illustrated, and an account is given of the type of product to which the different methods of casting are best suited.—J. C. R.

The Centrifugal Casting of Steel. G. V. Schmidt. (Neue Giesserei, 1948, vol. 33–35, Oct., pp. 101–104). A detailed description is given of the equipment and the moulding and centrifugal-casting technique successfully developed in Germany in 1944 for producing steel castings of high quality with a yield of about 75%.—R. A. R.

Centrifugal Casting in Germany with Particular Reference to the Production of Non-Ferrous Tubes. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1797: H.M. Stationery Office). A report is presented on visits to German foundries where centrifugal casting is practised. The works visited included Ruhrstahl A.G., Witten-Annen, where the following types of centrifugal castings were made: (1) Stainless steel cylinders (C 0·25%, Cr 15%, Mn 5·7%, Si 0·4–0·5%) for propeller-shaft liners; (2) cast iron cylinder liners; (3) vertical-spindle sand-spun steel castings; and (4) bi-metal cast tubes. The equipment, processes, and results obtained are briefly described.—R. A. R.

Some Practical Notes on Gases in Steel and Cast Iron. E. Eyt. (Fonderie, 1947, July, pp. 713–720). Gases are found in metals in the gaseous form, in the combined chemical state such as nitrides or oxides, or in the form of ions, such as hydrogen. The causes of the formation of blowholes, flakes, piping, and frothing are examined and consideration is given to various factors that result in the absorption of gases.—J. C. R.

Solidification Characteristics of Gray Cast Iron. J. E. Fifield and J. H. Schaum. (American Foundrymen's Association, 1948, Preprint No. 48-61). Solidification characteristics of grey cast iron were studied by bleeding partially solidified castings and obtaining curves at various points within castings identical with the bled castings which were poured simultaneously but allowed to solidify completely.

Studies of Solidification of White Iron Castings. V. Paschkis. (American Foundrymen's Association, 1948, Preprint No. 48-17, pp. 9–11). The author has studied the freezing rates of white iron castings using the electric analogy method.

The Principal Defects of Black-Heart Malleable Iron and Their Micrographic Diagnosis. H. Laplanche. (Fonderie, 1947, Feb., pp. 507–526; Mar., pp. 564–581). The author first analyses the defects which arise out of the chemical composition of the iron prior to graphitization, *e.g.*, an excessive carbon or silicon content (separately or together); too little silicon; too much sulphur (in relation to manganese); too much manganese (in relation to sulphur); too low manganese and silicon occurring together; too much phosphorus; too little carbon (below 1·5%); and presence of an element promoting or retarding graphitization. In the second part the author deals with defects which arise during malleablization, *e.g.*, annealing insufficiently or at too low a temperature or both of these factors together; annealing insufficiently or at the wrong temperature on the second heating; cooling too rapidly between 780° and 680°; overheating (temperature too high on the first heating); peeling; and brittleness due to low cooling below 600°. The various defects are illustrated and explained with reference to micrographs. A bibliography is included.—J. C. R.

Recommended Methods for Avoiding Porosity in Iron Castings. G. Joly. (Fonderie, 1947, June, pp. 692–693). After a brief analysis of the causes of porosity, the ideal chemical composition is discussed, and the means of achieving it by regulating the material charged in the cupola is outlined. J. C. R.

Casting Defects and Their Prevention. W. G. Reichert. (Macchine: Österreichischer Maschinenmarkt und Elektrowirtschaft, 1948, vol. 3, Sept., pp. 296–299). Moulding and casting techniques designed to reduce the number of casting defects are described.—R. A. R.

Causes of Rat Tail Casting Defect. (American Foundrymen's Association, 1948, Preprint 48-15). This paper describes work carried out by the A.F.A. Committee on Physical Properties of Iron Foundry Moulding Materials at Elevated Temperatures. The rat-tail phenomena were studied by making flat grey iron castings in a number of different sands. Two conditions that may cause the appearance of rat-tail defects are: (*a*) Insufficient void spaces between contact faces of adjacent sand grains, and (*b*) high mould stresses. Methods for the reduction or elimination of this type of defect are enumerated.—R. E.

Thin Iron Castings. J. Goffart. (Fonderie, 1947, Dec., p. 960). A summary is given of a paper in which the author discusses the factors influencing the choice of iron for thin castings.—J. C. R.

Study on Solidification of Steel Spheres. V. Paschkis. (American Foundrymen's Association, 1948, Preprint No. 48-17, pp. 11–16). The solidification of steel spheres was studied by comparing the results obtained in experiments using the Heat and Mass Flow Analyser (HMFA) with those obtained in experiments by Briggs and Gezelius.

Statistical Quality Control, A New Tool for the Foundryman. H. H. Johnson and G. A. Fisher. (American Foundrymen's Association, 1948, Preprint No. 48-7). The authors outline the principles underlying statistical methods of quality control, and present examples of their application in a steel foundry.—R. E.

An Approach to Quality Control in Castings Production. V. A. Simpson and G. K. Eggleston. (American Foundrymen's Association, 1948, Preprint No. 48-48: American Foundryman, 1948, vol. 13, June, pp. 55–56). The authors describe the practice at the plant of the Barnes Manufacturing Co., Mansfield, Ohio, for controlling the quality of castings—R. E.

Wet Type Dust Collectors. A. S. Lunely. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 667–669). Four general types of wet dust collectors, namely, spray or water curtain type, dynamic precipitation type, impingement type, and the combination type are discussed.—R. E.

Mechanical Aids for the Foundry. A. S. Beech. (Institute of Australian Foundrymen: Australasian Engineer, 1948, June 7, pp. 50–61). Recent advances in foundry mechanization and layout are described and discussed; sand preparation in particular is dealt with, and the author condemns any sand mill which has revolving rollers or mullers and a stationary pan, as the action on the sand must be that of rubbing, not grinding.—R. A. R.

The Modernization of Small and Medium Foundries with a View to Increasing Production. C. W. Schwenn. (Fonderie, 1947, Apr., pp. 612–621). The author outlines some directions in which increased mechanization can be introduced into small and medium iron foundries. Reference is made to the advantages of using an overhead electric monorail system and machines designed to avoid excessive manhandling of raw materials and castings.—J. C. R.

Installation of Mechanical Casting Plant for the Production of Small and Medium-Sized Parts. R. Lesage. (Fonderie, 1947, Feb., pp. 541–545). An account is given of the mechanization of a foundry producing parts weighing from 1–15 kg., with a plan of its layout.—J. C. R.

Foundry Mechanization and Modernization. R. Norguet. (Fonderie, 1947, Dec., pp. 913–922). A summary of this paper appeared in Foundry Trade Journal, 1947, vol. 83, Dec. 18, pp. 325, 332. (*See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 398.)

Mechanical Methods of Handling in Foundries. R. Kenner. (Fonderie, 1947, Dec., pp. 923–925). A summary is presented of the ways in which mechanical handling can be adopted in the foundry and the factors that influence the choice of system.—J. C. R.

The Mechanization of English Foundries. G. Joly. (Fonderie, 1947, Aug., pp. 759–769). A survey is presented of various ways in which English foundries have become increasingly mechanized, and illustrated descriptions are given of some of the machines employed.—J. C. R.

Modernization of the "Small" Foundry. L. B. Knight. (American Foundrymen's Association, 1948, Preprint No. 48-53). Practical suggestions for the modernization of foundries are discussed and some typical examples are described.—R. F. F.

Applications of Correlation in the Malleable Iron Foundry. R. G. Seidel. (American Foundrymen's Association, 1948, Preprint No. 48-22). The author presents examples and a discussion of correlation techniques and their possibilities as a useful tool applied to foundry problems.

Good Management Helps to Combat Economic Need. T. Geilenkirchen. (Neue Giesserei, 1948, vol. 33–35, July, pp. 16–20). The necessity for good management in German foundries is stressed and means of improving production under difficulties are discussed.—R. A. R.

The Economic Organization of the Metal-Casting Industry. G. Hücking. (Neue Giesserei, 1948, vol. 33–35, July, pp. 13–16). The state of development attained by the German foundry industry in 1945 and subsequent development in the American and British zones are reviewed.—R. A. R.

Foundry Training Course for College Graduates. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 200–203). *See* Journ. I. and S.I., 1948, vol. 158, Feb., p. 268.

The Problem of Recruits for the Foundry Industry. L. Frede. (Neue Giesserei, 1948, vol. 33–35, Oct., pp. 116–119).

HEATING FURNACES AND SOAKING PITS

Straightline Heating. S. M. Stoler. (Steel, 1948, vol. 123, Sept. 13, pp. 105–106). Billets for forging are delivered to a straight-line heating furnace, which is gas-fired and automatically controlled; they are cut to length for forging by a flame-cutting machine, travelling hot-saw, or flying shear as they emerge.—J. P. S.

Rapid Billet Heating with Gas. L. J. Stanbery and J. M. Brennan. (Iron Age, 1948, vol. 162, Aug. 26, pp. 82–85). A type of billet-heating furnace using natural gas, but capable of using coke-oven gas or oil fuel in emergencies is described. J. P. S.

Determination of Optimum Schedules for Heating Up Electric Furnaces. B. S. Meshel. (Promyshlennaya Energetika, 1948, vol. 5, Feb., pp. 7–10). [In Russian].

Reed Roller Bit Co. Streamlines Forging Department. (Modern Industrial Press, 1948, vol. 10, Apr., pp. 28, 30, 34: [Abstract] PERA Bulletin, 1948, vol. 1, Aug., p. 588). The improvements in forging practice are achieved mainly by a carefully thought out layout of presses and furnaces. The liberal use of conveyor belts, chutes, and semi-automatic handling equipment results in a large saving in floor area, manpower, and equipment, and eliminates much handling and lifting. A rotary furnace, used in conjunction with the 2500-ton Ajax forging press, is controlled by recording pyrometers, and rigid control of gas and air minimizes the scale formation on billets. Descaling is carried out hydraulically, by means of water jets under 1200 lb./sq. in. pressure. The finished forgings are annealed in a Mahr cycle-annealing furnace for a total of 13 hr.

Internal Thermal Conductivity Phenomena in Plates, Cylinders and Balls. W. Traupel. (Schweizer Archiv, 1948, vol. 14, July, pp. 193–205). A method is explained for calculating the changes with time of the temperature field and the amount of heat exchanged when a plate, a cylinder, or a ball is surrounded by a heat-transmitting medium the temperature of which is a given function of the time.—R. A. R.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat-Treatment: Conventional and Isothermal. J. M. Hodge. (SAE Journal, 1948, vol. 56, Sept., pp. 18–21). **Isothermal Heat Treatment.** J. M. Hodge. (Steel, 1948, vol. 123, Oct. 11, pp. 92–94, 112). The author explains, with diagrams, the differences between conventional hardening, annealing, and normalizing, and isothermal hardening, annealing, and normalizing.—R. A. R.

Steel Treatments. Practical Aspects of Isothermal Annealing, Austempering, Martempering and Deep Freezing. J. Shaw. (Iron and Steel, 1948, vol. 21, Sept., pp. 391–396; Oct., pp. 443–445). In this study of transformations in steel, four special types of heat-treatment, isothermal annealing, austempering, martempering, and deep freezing, are considered. Whilst these have limited useful applications they cannot generally replace conventional heat-treatment methods. Accurate isothermal and anisothermal transformation data are essential when considering special treatments for particular steels. Frequent reference is made to the work of various investigators in this field.—J. C. R.

Modified Martempering. W. Olson and G. Nevis. (Industrial Gas, 1948, vol. 26, Apr., pp. 10–11, 16, 18–19).

Recent French Work on Stepped Quenching. G. Delbart. (Bulletin de la Société Royale Belge des Ingénieurs et des Industriels, 1948, Série A, No. 3, pp. 180–192). A detailed survey is presented of the research work on stepped quenching undertaken by French investigators. A bibliography of twenty-two references is appended.—J. C. R.

S-Curves and Nomenclature for Heat-Treatment. U. Wyss. (Schweizer Archiv, 1948, vol. 14, Apr., pp. 127–128). German and English heat-treatment terms are briefly discussed. R. A. R.

Heat-Treating Principles and Their Applications to Salt Baths. H. Solakian. (Machinist, 1948, vol. 92, July 10, pp. 316–318; Aug. 7, pp. 438–441; Oct. 2, pp. 754–757). Heat-treatment principles and the uses and types of salt baths are discussed. The methods of heating baths, by immersion units, by open resistance units, and by immersion electrodes are compared, and some practical notes on pots, salts, and conveyors are given.—R. F. F.

Effects of Alloying Elements on the Heat Treatment of Steel. J. McAfee. (Australian Institute of Metals: Australasian Engineer, 1948, Aug. 7, pp. 57–67). After a brief historical summary of heat-treatment the effects of alloying elements are comprehensively dealt with in the following sections: (1) Effects under equilibrium conditions; (2) classification of alloy steels; (3) effects on austenitization; (4) effects on isothermal subcritical transformation of austenite; (5) effects on rate of isothermal subcritical reactions; (6) effects on martensite formation; and (7) effects on the tempering of martensite.—R. A. R.

The Physical-Chemical Fundamentals of the Gas-Carburization of Iron. W. Baukloh. (Die Technik, 1948, vol. 3, May, pp. 224–226). The advantages of the gas-carburizing process are pointed out, and the physical-chemical requirements for case-hardening iron in CO-CO_2 and in CH_4-H_2 mixtures are discussed with notes on the manner in which alloying elements affect the equilibria.—R. A. R.

Control of Carbon Content during Heat Treatment of Steel in Amosphere Furnaces. W. H. Holcroft and E. C. Bayer. (Materials and Methods, 1948, vol. 28, Aug., pp. 59–61). Curves are presented which enable the carburizing potential of a heat-treatment atmosphere at temperatures of 1400°, 1500°, 1600°, 1700°, and 1800° F. to be rapidly determined when the CO and CO_2 contents of the atmosphere are known. Examples of their use are given.—R. A. R.

Heat Treatment of High-Speed Steel. J. G. Ritchie. (Australian Institute of Metals: Australasian Engineer, 1948, Aug. 7, pp. 38–49). Recent research on the heat-treatment of 18/4/1 tungsten–chromium–vanadium high-speed steel is reviewed. The theory is first explained and then the practical aspects of the changes in properties and structure obtainable by variations in the composition and heat-treatment are dealt with. Most of the paper covers normal hardening and tempering treatments. In a short reference to other treatments the author states that, provided tempering is properly completed, subzero cooling has no advantage to offer.—R. A. R.

Electrical Heating of Steel Strip for Continuous Processing. A. P. Ryan and F. E. Ackley. (Iron and Steel Engineer, 1948, vol 25, Aug., pp. 66–78). The authors deal with the furnace method and with the resistance and induction methods for the continuous heating of steel strip either for heat-treating the material or for flowing electrodeposited

tin coatings on the strip. The chief factors which influence the type, size, and features of a heating furnace are enumerated. A curve is included which shows that, when the surface emissivity of the strip is high, most of the heat transfer is by radiation, but when the emissivity is low, the heat transferred by convection is important in determining the rate at which the strip will heat. Other curves show that the rate of heating a strip is inversely proportional to its thickness and that strip heats to high temperatures more quickly than to low temperatures. The designs of the roller-hearth type, tower type, and catenary types of furnace are shown, and the control of strip-heating furnaces is touched upon. The general problems involved in the design and operation of resistance equipment is discussed and a typical resistance-heating arrangement using polished rolls is illustrated. The theory of induction heating is considered, two types of induction equipment are described, and the applications of this method are indicated.—R. E.

Rotary Hearth Furnaces Find Many Uses in Heating Steel. R. E. Buckholdt. (Blast Furnace and Steel Plant, 1948, vol. 36, Aug., pp. 937–941). The Salem Engineering Co., Salem, Ohio, has built a variety of rotating-hearth furnaces for the heat-treatment of steel and non-ferrous metals, both gas and oil-fired.—J. P. S.

Special Furnaces Developed for Producing Hollow Steel Propellors. R. M. Hortvet. (Iron Age, 1948, vol. 162, Sept. 16, pp. 72–79). Furnaces are described for the heat-treatment of aircraft propellers built up by forging and welding.—J. P. S.

The Heat Treatment of Dies. R. A. Smith. (Machinery, 1948, vol. 73, Sept. 16, pp. 440–443). The various types of dies in common use with the types of steels employed are described. The heat-treatment operation for each case and the most suitable type of furnace are discussed. Special reference is made to salt-bath installations and methods of handling dies.—R. F. F.

Conventional *versus* Salt Bath Hardening of Cast Iron Cylinder Liners. G. M. Lahr. (American Foundrymen's Association, 1948, Preprint No. 48-42). To reduce the difficulties, such as distortion, growth, scaling, and cracking, encountered when hardening cast-iron liners by the conventional quench and tempering method, the adaptation of salt-bath quenching procedures to hardening liners was investigated. Two salt-bath cycles were compared to the conventional method and the equipment used and results obtained are described.—R. F. F.

Surface Hardening. S. Förster. (Werkstatt und Betrieb, 1948, vol. 81, June, pp. 151–157). All modern methods of hardening steel are reviewed with special reference to induction hardening for which examples are given of the calculation of power requirements and size of coils. Details of a method of measuring the secondary current are also given.—R. A. R.

Heat-Treatment of Carbon and Alloy Steels for Vehicles and Engines. D. C. G. Lees. (Metal Treatment, 1948, vol. 54, Summer Issue, pp. 73–74). The A.E.C. Works at Southall, Middlesex, carries out carburization of many motor-vehicle parts by conventional pack methods in oil-fired muffle furnaces; core-refining takes place in gas-fired furnaces or salt baths, the latter type being also used for simple hardening. Final tempering is done in gas-fired oil baths. A control test-piece is included in each case-hardened batch.—J. P. S.

Selective Hardening of Wear Surfaces. J. F. Libsch and R. D. Guess. (Tool Engineer, 1948, vol. 20, pp. 31–32).

Hardenability Control for Alloy Steel Parts. A. L. Boegehold. (Metal Progress, 1948, vol. 53, May, pp. 697–709). Discussing the tentative specifications for hardenability established by the Society of Automotive Engineers and the American Iron and Steel Institute, the author concludes that "H-band" limits, *i.e.*, the range of hardness obtained by the Jominy end-quench test, are a better guide to the hardenability of steel than its chemical analysis. Buying steel by analysis rather than by the "H-band" may lead to a wide spread of hardness values at the surface of hardened articles.—J. P. S.

Bright Hardening and Tempering Tiny Parts. H. L. Hovis and A. W. Marks. (Machinist, 1948, vol. 92, June 5, pp. 153–156; June 19, pp. 218–221). Former methods of heat-treating precision instrument parts having proved unsatisfactory, investigations were carried out to improve the heat-treating process. Bright-hardening in an atmosphere of carbon monoxide was found to have marked advantages over pack-hardening. Bright tempering in a hydrogen atmosphere prevents discolorations, avoids the need for degassing, increases output, and gives a better finish. Tempered tools may be advantageously quenched in salt baths.—M. A. V.

Economic Aspects of Radio-Frequency Heating. L. M. Duryee. (Electrical Engineering, 1948, vol. 67, Aug., p. 747). A table of the proposed band-number designations for the frequency bands used in high-frequency heating is presented together with some cost data from experience in the United States in the use of the process. One example compares the costs of flame-tempering and induction tempering of axe heads. Another example compares the times for baking cores in ovens with drying by dielectric heating.—R. A. R.

Heating Metals by Induction and High-Speed Gas Methods. H. R. Clauser. (Materials and Methods, 1948, vol. 28, July, pp. 55–59). The efficiencies and costs of heating for hardening and forging by high-frequency induction, and by gas with radiant cup-shaped ceramic burners, are compared and the metallurgical results obtained are reviewed. Under the conditions investigated at the Battelle Memorial Institute both the capital cost of the equipment and the operating costs are less for gas. With gas the minimum depth of hardened layer is about 0·125 in., whereas with induction heating a layer only 0·010–0·015 in. deep can be hardened.—R. A. R.

High Frequency Heating—Its Application to Production Engineering. A. L. Simmons. (Institute of Production Engineers: Australasian Engineer, 1948, June 7, pp. 65–73). After briefly touching upon the production of high-frequency power, its application for surface-hardening gear teeth and crankshafts, and through-heating for forging, welding and other joining processes are discussed with examples; finally, the dielectric heating of non-conductors is described.—R. A. R.

The Rotary Induction Heater. G. Brunner and A. Tschalær. (Brown Boveri Review, 1947, vol. 34, Apr.–May, pp. 81–85). A new method of heating metal plates and billets inductively for rolling, stamping, or forging is described. It can readily be adapted to rolling-mill conditions. With this equipment the eddy currents are induced in the work by rotating D.C. magnets. Auxiliaries such as frequency converters and variable condensers are not required, so that the whole equipment costs about half as much as that for conventional induction heating with medium frequencies, and only a little more than an electrical resistance furnace plant. It is particularly suitable for intermittent service.—R. A. R.

The Determination by a Calorimetric Method of the Power Taken off the Oscillatory Circuit during Heating by High-Frequency Current. S. M. Gamazkov. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 880–881). [In Russian]. Two types of flow calorimeter are described for the determination of the power being absorbed from the oscillatory circuit by the heated object during the H.F. induction heat-treatment of, for example, steel parts. The walls of the calorimeter should be made of the same material as that being heated.—S. K.

Transformation during Heating with High-Frequency Currents. I. N. Kidin. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Jan., pp. 75–84 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, July, p. 34). An account is given of phase transformations of steel during thermoelectric treatment. It was found that the characteristic feature of the transformation was the specific action of the current on the ferrocementite mixture and consolidation of the lines of force at the phase boundary, resulting in quicker formation of austenite nuclei than in other methods of heat-treatment.

Some Peculiarities in the Behaviour of Steel during Rapid Heating by Means of High-Frequency Electric Current. M. G. Lozinskii. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques, 1948, Jan., pp. 109–130 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, July, p. 34). Three types of structural steels were investigated. The zone of hardening was found to increase sharply in size with decrease in the duration of the heating cycle and correspondingly increased with higher rate of heating. The results, which are charted ahd illustrated, indicate the effect of various alloying elements on displacement and size of the hardened zone.

Carbo-Nitriding—A Case Hardening Process. E. C. Bayer and M. R. Larson. (Steel Processing, 1948, vol. 34, May, pp. 264, 267, 272). The author describes a radiant-tube continuous case-hardening furnace made by Holcroft and Co.,

Detroit. The atmosphere consists of a non-carburizing mixture of CO, hydrogen, and nitrogen, obtained by catalysing natural gas (methane) to which is added propane or natural gas, and ammonia. The hydrocarbon gas carburizes the work while the ammonia dissociates at working temperature giving a nitriding effect ; the balance of these two is adjusted as required.—J. P. S.

Controlled Atmosphere Cycle Annealing. T. A. Frischman. (Iron Age, 1948, vol. 162, Sept. 9, pp. 72–77). A five-zone, controlled atmosphere furnace has been constructed in which up to eight grades of low to medium carbon steels can be simultaneously put through an annealing cycle. Radiant tubes are used for heating ; the protective atmosphere is produced by the incomplete combustion of gas.—J. P. S.

Influence of Manganese Content on the Annealing of Black Heart Malleable Iron. G. Joly. (Fonderie, 1947, July, pp. 734–735). Sulphur and manganese both have a restraining effect on the graphitization of white cast iron, but manganese sulphide does not have this effect. In theory therefore, the manganese content should equal 1·72 times the sulphur content, but in practice, the manganese content may exceed this figure by up to 0·25% and should exceed it by at least 0·10%.—J. C. R.

Malleable Annealing Furnaces. G. Joly. (Fonderie, 1947, Dec., pp. 965–970). After briefly outlining the heat-treatment processes used in the malleablization of white- and black-heart iron, the author surveys different types of annealing furnaces.—J. C. R.

Annealing Malleable Iron Castings. E. G. Billhardt. (Iron Age, 1948, vol. 162, Aug. 19, pp. 86–89). The works of Lake City Malleable, Inc., Ashtabula, O., operates electrically heated elevator furnaces for annealing malleable iron castings ; these are arranged in pans, so that the car-load of castings, after a period in a high-temperature furnace, passes to a low-temperature furnace to finish off the annealing cycle.—J. P. S.

Electric Oven Annealing of Malleable Iron Castings. F. W. Jacobs. (Foundry, 1948, vol. 76, Sept., pp. 68–73, 129). An illustrated description is given of extensive electric furnace equipment for annealing malleable iron castings at the foundry of Lake City Malleable Co., Cleveland, Ohio. There are six 16-ton and one 4-ton units. Each 16-ton unit consists of one high-temperature and one low-temperature chamber ; each oven measures 32 ft. 3 in. × 11 ft. 6 in. × 27 ft. high. The furnaces stand between columns with lifting machinery which raises the whole furnace and the car with its load of castings about 9 ft. above floor level. They are heated by electric resistance elements. The baskets and grids holding the castings are of 35/15 chromium–nickel steel. About 100 tons of castings can be treated per day.—R. A. R.

Electric Furnaces for the Wire Industry. H. J. Tucker and J. A. Monks. (Wire Industry, 1948, vol. 15, June, pp. 385–386 ; July, pp. 451–452 ; Aug., pp. 519–521). The first part of this article describes bell type furnaces, pit and vertical furnaces, continuous strand furnaces, and continuous furnaces in which the work moves on conveyors or rollers, for the bright-annealing of ferrous and non-ferrous material. The second part covers generators for protective atmospheres, and continuous wire-patenting furnaces. In the third part the layout of a continuous hot-dip pickling, fluxing, and galvanizing line is described.

Portable Cover Sheet Annealing Furnaces. L. G. A. Leonard. (Metallurgia, 1948, vol. 38, May, pp. 43–46). A new type of portable-cover furnace intended for the annealing of silicon-steel sheet in batches is directly gas-fired. The bottom is a cast steel pan, resting on brick piers, between which the exit gases pass. Metallic recuperators are used to preheat combustion air.—J. P. S.

Continuous Furnace Simplifies Annealing Austenitic Stainless. L. F. Spencer. (Iron Age, 1948, vol. 162, Sept. 23, pp. 84–88). An electrically heated continuous furnace for annealing pressed austenitic stainless-steel components in a protective atmosphere is described.—J. P. S.

Welding Stresses Dissipated by Low Temperature Process. T. W. Greene. (Steel, 1948, vol. 123, Aug. 9, pp. 78–82). Welding stresses can be dissipated by progressive heating followed by water quenching. This is applied by travelling oxy-acetylene blowpipe flames, 6 in. behind which move water sprays. The expansion of the plate produces plastic stretch in the weld material which, on return to normal temperatures no longer imposes a stress on the structure. Details are given of the application of this to ships' hulls, pressure-vessels, and welded gasholders.—J. P. S.

Theoretical and Practical Researches on Isothermal Quenching. A. Sourdillon. (Métallurgie, 1948, vol. 80, Sept., pp. 11–13, 15–17, 19). In this review of the work of various investigators on isothermal transformations, the author deals particularly with steels of varying carbon content and special steels, the stabilization of complex austenites in the Ar_3 range, and isothermal heat-treatment processes. The advantages and disadvantages of these treatments are discussed. A bibliography of thirty-six references is appended.—J. C. R.

Practical Aspects of Quenching below the Critical Temperature. W. J. Holcroft and H. J. Hammond. (Steel, 1948, vol. 123, Sept. 20, pp. 106, 108). A new installation is described for the carbonitriding of automobile parts. These are heated in a conveyor furnace in an atmosphere of generator gas, hydrocarbon gas, and ammonia, by radiant tubes ; they are then cooled in the furnace to a temperature below that at which the core will harden on quenching, but above the critical temperature of the case, and then quenched.—J. P. S.

FORGING, STAMPING, DRAWING, AND PRESSING

Hard Die Inserts. F. Lovell. (Steel, 1948, vol. 123, Aug. 23, p. 108). Inserts of high carbon, high chromium tool steel have been fitted to the dies used in the manufacture of a U-bolt of 0·35–0·45% carbon steel. Die life has been increased by 400%.—J. P. S.

Alloy Die Steels. L. Sanderson. (Metallurgia, 1948, vol. 38, July, pp. 147–152). Die steels for cold and hot working are considered individually and their selection, manufacture, and subsequent heat-treatment are discussed.—P. W.

Fasteners. J. A. Stewart. (Australian Institute of Metals : Australasian Engineer, 1948, May 7, pp. 70–75). The forging of bolts and rivets, their uses, and specification requirements are discussed.—R. A. R.

Extrusion Forging Ready for Mass Production. (Automotive Industries, 1948, vol. 98, Apr. 1, pp. 40, 60 : [Abstract] : Bulletin of the British Non-Ferrous Metals Research Association, 1948, June, p. 183). This is a note on extrusion forging in steel of automobile front spindles at Fords. No details are given of the actual extrusion forging process, but the properties and structure of the spindles are compared with the previously hammer-forged products.

Tool Steels for Cold-Forging. K. W. Michler. (Industrie Rundschau, 1948, vol. 3, No. 3, pp. 6–7 : British Abstracts, 1948, BI, Aug., col. 414). The steel contains C 0·95–1·00%, Si 0·15–0·30%, Mn 0·20–0·30%, P $\gtrless$ 0·02%, and V 0·20–0·30%, and is case-hardened by quenching from 780–800° (870°) in air, oil, or water and then annealed at 230–260°. The normal depth of hardening is 2·5–5·0 mm.

Large Stainless Steel Tank Heads Fabricated by Spinning. (Materials and Methods, 1948, vol. 28, Aug., pp. 56–58). A brief illustrated description is given of the spinning method of shaping circular plates of 18/8 stainless steel from 36 to 102 in. in dia. to make ends for milk storage tanks.—R. A. R.

The Application of Deep Drawing and Pressing to Gas Turbine Engines. H. E. Lardge. (Sheet and Strip Metal Users' Technical Association : Sheet Metal Industries, 1948, vol. 25, Aug., pp. 1603–1608). Descriptions are given of the drawing operations applied to mild steel, 18/12 stainless steel, and Nimonic 75 (Ni 80%, Cr 20%) in the manufacture of parts for the combustion system of gas turbine engines.—R. A. R.

Effect of Composition and Manufacture on the Manipulative Properties of Medium Carbon Steel With Special Reference to Banded Structure. K. G. Lewis. (Iron and Coal Trades Review, 1948, vol. 157, Sept. 10, pp. 557–563 ; Sept. 17, pp. 623–627). An investigation into the correlation between certain items of composition and manufacture and the types of defect which occur in the rotary-piercing and rolling of seamless hollow billets of medium carbon steel is described, together with recommended procedure or modifications in procedure, based on those correlation factors which have been shown to be significant. Particular attention is paid to the causes underlying banding and to the relationship between phosphorus segregation and internal surface defects in the rotary-piercing of hollow billets. In the second part the author deals with various theories of banding and how modification of existing procedures or adoption of a different one may eliminate or reduce the effect. The mechanical considerations arising from rotary-piercing practice are also considered.

Wire Mill Practice. W. F. G. Kerley. (Wire Industry, 1948, vol. 15, Sept., pp. 589–590). Conclusion of a series of articles (*see* Journ. I. and S.I., 1948, vol. 160, Oct., p. 225). The structure of diamonds, the direction of drilling in relation to the crystal cleavage planes, and mounting diamond dies for wire-drawing are discussed.—R. A. R.

Expands Wire Producing Facilities. (Steel, 1948, vol. 123, July 12, pp. 114–116). **J & L Modernizes Wire Mill.** (Wire and Wire Products, 1948, vol. 23, July, pp. 580–582, 623). A description is given of some of the new plant being installed by the Jones and Laughlin Steel Corp.; it includes 55 wire-drawing machines, a rod cleaning unit, annealing furnaces and 14 nail-making machines.—R. A. R.

MACHINERY FOR IRON AND STEEL PLANT

Specialized Rolling Stock for Iron and Steel Works. Part I—Transfer Cars. T. H. Stayman. (Journal of The Iron and Steel Institute, 1948, vol. 160, Oct., pp. 197–199).

Specialized Rolling Stock for Iron and Steel Works. Part II—Scale Cars. D. R. Brown. (Journal of The Iron and Steel Institute, 1948, vol. 160, Oct., pp. 200–204).

Specialized Rolling Stock for Iron and Steel Works. Part III—Hot-Metal Ladles. D. R. Brown. (Journal of The Iron and Steel Institute, 1948, vol. 160, Oct., pp. 204–207).

Specialized Rolling Stock for Iron and Steel Works. Part IV—Slag Ladles. T. H. Stayman. (Journal of The Iron and Steel Institute, 1948, vol. 160, Oct., pp. 207–210).

Specialized Rolling Stock for Iron and Steel Works. Part V—Ingot Bogies. T. H. Stayman. (Journal of The Iron and Steel Institute, 1948, vol. 160, Oct., pp. 211–212).

Compressed Air Employed in the Fabrication of Plant. (Blast Furnace and Steel Plant, 1948, vol. 36, Sept., pp. 1116–1117). Compressed air is used in a number of operations in the trimming, bending, and automatic welding of pipe from steel sheet. Pneumatic tools are also employed in the structural and machine shops.—J. P. S.

How Gas Engines Serve Today's Steel Mills. W. M. Cline, jun. (Power, 1948, vol. 92, Jan., pp. 102–104).

LUBRICANTS AND LUBRICATION

Some Modern Aspects of Steel Plant Lubrication. C. E. Pritchard. (Lubrication Engineering, 1947, vol. 3, Dec., pp. 64–68).

Gear Lubrication in Modern Industrial Applications. A. F. Brewer. (Steel, 1948, vol. 123, July 12, pp. 88–92, 122). The requirements of lubricants for gears of different types operating under different conditions of load and speed are discussed.—R. A. R.

Industrial Uses of Some Polyether Synthetic Lubricants. W. H. Millett. (Iron and Steel Engineer, 1948, vol. 25, Aug., pp. 51–60). The properties and applications of non-hydrocarbon synthetic lubricants, known under the trade name of "Ucon," are described.—R. E.

Ways and Means of Lubricating SKF Rolling Bearings. (Ball Bearing Journal, 1947, Nos. 3 and 4, pp. 62–73). Grease, oil, and oil-mist lubrication for all types of rolling bearings is discussed with descriptions of the equipment used.—R. A. R.

Drawing Lubricants. W. J. Haring. (New England District Pressed Metal Institute: Steel Processing, 1948, vol, 34, Feb., pp. 84–87). **Selecting Drawing Lubricants.** W. J. Haring. (Steel, 1948, vol. 122, Apr., 19, pp. 86–88, 91). The difference between lubrication for bearings and for pressing operations is pointed out, and boundary lubrication, the chain structure of fats, fatty acids, and scraps, and the use of sulphur-bearing and chlorinated lubricants are discussed. R. A. R.

Practical Problems of the Ageing of Lubricants. M. Gratzl. (Die Technik, 1948, vol. 3, June, pp. 267–270). The ways in which the ageing of engine oils manifests itself are described and investigations on the nature of the products of the ageing are reported.—R. A. R.

WELDING AND FLAME-CUTTING

The Drawing and Dimensioning of Welded Joints. A. Kunert. (Die Technik, 1948, vol. 3, July, pp. 320–324). Conventional signs and methods of indicating dimensions on drawings of welded components are described.—R. A. R.

Fundamental Questions Relating to Materials for Welded Structures. F. Campus. (Schweizer Archiv, 1948, vol. 14, May, pp. 129–137). The author discusses the selection of material for welds in the light of the results of research undertaken to establish the causes of the failure of the welded bridge at Hasselt, and subsequent work on the safety of welded structures.—R. A. R.

The Metallurgical Aspects of Fusion Welding in Relation to the Weldability of Steels. H. Granjon. (Sheet Metal Industries, 1947, vol. 24, Dec., pp. 2475–2477; 1948, vol. 25, Feb., pp. 367–371; Sept., pp. 1837–1840). A general account is given of investigations carried out at the Institut de la Soudure on the structural changes during the fusion welding (oxy-acetylene or electric arc) of steel. The thermal cycle in welding is compared with the common heat-treatment cycles.

Welding Arc Temperatures. W. R. Chynoweth, J. U. Jeffries, R. J. LaPante, R. J. Krieger, and G. H. Fett. (Welding Journal, 1948, vol. 27, Aug., pp. 426-s–427-s). Conditions in the welding arc are subject to extremely rapid fluctuations of potential and current, so that its temperature is difficult to determine. The authors, however, by study of a formula derived for the analysis of the high-temperatures occurring in the stars, and involving ion density, electronic charge, pressure, and temperature, establish that the voltage gradient in the arc stream and not the arc voltage is the important factor, and that the current density, and not the current itself, controls temperature; increase in current density, provided the voltage gradient does not change at too great a rate, will increase the arc temperature.—J. P. S.

Electrical Characteristics of the Arc in "Heliarc" Welding. H. T. Herbst. (American Institute of Electrical Engineers: Welding Journal, 1948, vol. 27, Aug., pp. 600–604). In heli-arc welding of stainless steels, magnesium, and aluminium either direct or alternating current may be used. In reverse polarity direct current welding, *i.e.*, with the electrode positive, greater cleaning of the work by removal of surface oxide occurs; in alternating current welding this oxide film causes partial rectification of the current.—J. P. S.

The Weldability of Alloys for High Temperature Service. G. E. Linnert. (Welding Journal, 1948, vol. 27, Aug., pp. 385-s–405-s). A new laboratory test has been devised to duplicate the conditions in which gas-turbine buckets are welded to the turbine wheel. Tests employing submerged-arc and manual-arc welding to join a number of alloy combinations, and in which a number of variables, such as different filler rods and a range of preheating temperatures were introduced, have been performed. The principal defect encountered was 'interbucket junction extension cracking,' a fissure-like defect running transversely through the weld-metal from the notch between adjacent buckets. The amount of this cracking is influenced to some degree by the welding process employed, and to a minor extent by preheating; the major factor is, however, the susceptibility of the weld metal to segregation. This is a function of weld-metal composition, cooling rate, and possibly other factors; correlation has not, however, been established.—J. P. S.

The Vierendeel Structural Work of the Ilva Steelworks, Naples, Italy. A. Bozzarelli. (Ossature Métallique, 1948, vol. 13, Oct., pp. 435–438). An illustrated description is given of the outside structural work of the welded Vierendeel type, housing the new basic-Bessemer plant at the Ilva steelworks.—J. C. R.

Spot Welding of Mild Steel in Production. N. E. Wheeler. (Welding Journal, 1948, vol. 27, Aug., pp. 613–614). Efficient spot welding of mild steel can be obtained by attention to design, control, training of operators, and machine maintenance. Regular inspection of welds is necessary.—J. P. S.

Spot Welding of Low Carbon Mild Steel Sheet. (Transactions of the Institute of Welding, 1948, vol. 11, Oct., Welding Research, pp. 83r–86r). This is the interim report of the FR 6 Committee of the British Welding Research Association, which is preparing a code of practice for the spot-welding of mild steel. The electrode tip diameter, pressure, weld time, welding current, edge distance, and minimum weld pitch, to obtain good spot welds in 14, 16, 18, and 20 S.W.G. sheet are specified, together with the characteristics of the weld which should be produced.—J. P. S.

Welding Body Sections at Fords. D. Criteser. (Iron Age, 1948, vol. 162, Sept. 9, pp. 88–94). Extensive mechanization is employed in the resistance welding of doors, floors, hoods, etc., at the River Rouge Plant of the Ford Motor Co.—J. P. S.

Welding Banjo Type Axles at Ford. W. Kroy. (Iron Age, 1948, vol. 162, Sept. 23, pp. 96–101). A variety of welding methods, (butt-welding, spot-welding, projection-welding, and

submerged-arc welding) are used under automatic control in the assembly of rear axles for Ford cars.—J. P. S.

Chainmaking.—Present Day Practice. R. B. Vasey. (Steel, 1948, vol. 123, Oct. 4, pp. 76–78). Types of chain and the manufacture of steel chain by resistance welding are described.—J. P. S.

Welding of Tools and Dies. T. W. Girdler. (Australian Welding Institute: Australasian Engineer, 1948, July 7, pp. 52–55). Metallic arc welding procedures for repairing and fabricating tools and dies are discussed.—R. A. R.

Welding Screw Shafts to Castings. P. H. Setzler. (Iron Age, 1948, vol. 162, Aug. 26, pp. 93–94). Steel shafts 7 in. to 13 in. in dia. are thermit-welded to cast steel parts; a normalizing heat-treatment at 1650° F. (900° C.) is given before final machining.—J. P. S.

Here's a Way to Preheat Castings. F. C. Geibig. (Welding Journal, 1948, vol. 27, Aug., pp. 591–592). A temporary brick furnace is described in which damaged castings are preheated with charcoal before repairs by welding are made. J. P. S.

Bonze-Welding of Cast Iron. T. J. Palmer. (Iron and Coal Trades Review, 1948, vol. 157, Aug. 13, pp. 353–356). The principles involved and the advantages and disadvantages in bronze-welding cast iron are reviewed. Among the aspects dealt with are the composition of the filler metal, the nature of the welded bond, most recent methods of surface preparation, preheating, and the procedure of bronze-welding and its application.—J. C. R.

Furnace Brazing Simplifies Product Design. H. M. Webber. (Steel, 1948, vol. 123, Oct. 4, pp. 79–84, 114). The manufacture of a number of components of various types from stampings, tubes, and machined parts by furnace brazing is described. Brief reference is made to the furnace brazing of stainless steel parts without flux in a protective atmosphere of hydrogen or cracked ammonia.—J. P. S.

Effect of Welding Practice on Abrasion Resistance of Hard Facings. R. D. Haworth. (Iron Age, 1948, vol. 162, Oct. 7, pp. 82–87). Built-up weld-metal beads show better results in an abrasion-testing machine when deposited by means of the oxy-acetylene torch than when electric-arc methods are used. This is largely due to the dilution of the weld metal by the base metal which occurs in the latter case.—J. P. S.

Hard Surfacing by Fusion Welding. H. S. Avery. (Steel, 1948, vol. 123, Oct. 11, pp. 96–100, 107, 110, 112). Various types of hard-facing alloy for application by gas- or arc-welding are described, including high-carbon chromium–cobalt–tungsten alloys, nickel–chromium alloys containing boron which owe their wear resistance to the formation of chromium boride, austenitic manganese steels, and high chromium cast irons. The limitations of the wet-sand methods of determining wear resistance are discussed.—J. P. S.

CLEANING AND PICKLING

Trichlorethylene. P. Flament. (Galvano, 1945, vol. 14, July, pp. 6–7; Aug., pp. 6–8; Sept., pp. 7–9; Dec., pp. 7–9), The properties of trichlorethylene, the processes of cleaning, and apparatus are described.—R. F. F.

Recent Progress in Cleaning Technique. G. Cros. (Fonderie, 1947, Dec., pp. 930–932). A survey is made of advances in the cleaning of castings by sand and grit blasting using compressed air, centrifugal sand slingers, and sand blast tunnels.—J. C. R.

The Effect of Additions to Pickling Acids. K. Wickert. (Archiv für Metallkunde, 1948, vol. 2, Feb., pp. 56–62). The theory of the actions of accelerators and inhibitors in acid pickling solutions is briefly explained, and formulæ for expressing the efficiency of the pickling process are derived. Details are given of several series of pickling tests in which the rates of solution of ingot iron and ferric oxide in hydrochloric acid with and without additions of accelerators and inhibitors were determined. From the data obtained the efficiencies of the accelerators and inhibitors are quantitatively assessed.—R. A. R.

What is a Clean Surface? J. Liger. (Galvano, 1947, vol. 16, Jan., pp. 7–8). This is a critical discussion of a paper by E. H. Lyons which appeared in the Transactions of the Electrochemical Society, 1945, vol. 88, pp. 281–295. (*See* Journ. I. and S.I., 1946, No. I, p. 9A).—R. F. F.

The Electrochemical Treatment of Iron Wire Used in the Manufacture of Safety Glass. V. P. Mashovec and A. P. Obukhov. (Journal of Applied Chemistry, U.S.S.R., 1947, vol. 20, No. 3, pp. 219–224 [in Russian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 8, p. 1520). The necessity for cleaning and complete degasification of the wire is discussed and optimum operating conditions are outlined.

Preparation of Metal Surfaces for Organic Coating. G. R. Hoover. (Corrosion, 1948, vol. 4, Aug., pp. 399–411). Surface preparation of steel in steelworks, solvent cleaning, sand-blasting, alkaline and emulsion cleaning, and chemical treatments before organic coating are discussed.—R. F. F.

Clean Iron and Steel Surfaces: Some Fundamental Considerations with Particular Reference to Vitreous Enamelling. T. P. Hoar. (Institute of Vitreous Enamellers: Sheet Metal Industries, 1948, vol. 25, Sept., pp. 1805–1808, 1826). The author explains briefly the functions of the various degreasing, pickling, and rinsing processes from the point of view of fundamental chemical knowledge, at the same time keeping the practical operations in mind.—R. A. R.

Electrolytic Preparation and Treatment of Soft Grey Iron. (Galvano, 1946, vol. 15, Mar., p. 14). The special technique, required for the preparation and the plating of soft grey iron, is briefly described.—R. F. F.

The Sodium Hydride Process. A New Method of Descaling Metals. N. L. Evans. (Journal of the Electrodepositiors' Technical Society, 1948, vol. 24, pp. 9–13). A detailed account is given of the operation of the sodium hydride process, the plant used and the precautions to be taken, and its applications and advantages as compared with acid pickling.—J. C. R.

Cleaning—Preparation of Metals prior to Electrodeposition. R. Macnair. (Metal Industry, 1948, vol. 73, Sept. 10, pp. 206–208; Sept. 24, pp. 247–249). The available methods of cleaning metals before plating are reviewed.—R. A. R.

Pretreatment of Construction Steel for Painting. J. F. Bogtstra. (Werfkroniek, 1948, vol. 21, pp. 107–111: Chemical Abstracts, 1948, vol. 42, Aug. 20, col. 5823). The importance of the removal of the mill scale from the steel, besides rust and dirt, before painting is emphasized. Flame cleaning, treatment with a dry and wet sand blast or a steel blast, and pickling are described for this purpose. For an especially long life of the paint on steel structures the use of a zinc coating before painting is recommended.

Continuous Flow Internal Pipe Pickling. (Iron and Steel Engineer, 1948, vol. 25, Aug., pp. 102–103). Particulars are given of the methods and equipment used at the South Philadelphia works of the Westinghouse Electric Corporation for the internal pickling of pipe assemblies for oil lines. The pipe assemblies are carried through the pickling room on tray cars and subjected to hot pickling in caustic soda, hydrofluoric acid, and sulphuric acid solutions with intermediate rinsing. The pickling solutions and rinse waters are pumped through the assemblies, and pressure is maintained by blocking up the pipe exits with slotted wooden plugs through which the fluid can flow slowly. After pickling, the pipe assemblies are given an atomized oil spray.—R. E.

Metal Surface Preparation for Organic Coatings. A. Gellman. (Electroplating, 1948, vol. 1, Aug., pp. 511–520, 530). After outlining the reasons for surface preparation, the author discusses the degreasing of sheet steel by chemical means and organic solvents, mechanical cleaning, acid pickling, and passivation. An account is also given of the preparation of aluminium and zinc surfaces.—J. C. R.

Hot Degreasing Using Alkaline Solvents. (Galvano, 1945, vol. 14, June, pp. 7–8). Six basic formulæ for degreasing baths are given.—R. F. F.

Simple Electrolytic Degreasing or Combined Degreasing and Copper Plating. (Galvano, 1945, vol. 14, Apr., pp. 7–8). The advantages and disadvantages of both methods are compared.—R. F. F.

The Operation and Maintenance of Electrolytic Degreasing Baths. (Galvano, 1946, vol. 15, Sept., pp. 7–8; Oct., pp. 7–8). Some common errors in the operation and maintenance of degreasing baths are discussed.—R. F. F.

Surface Treatment of Stainless Steels. H. Gros. (Galvano, 1946, vol. 15, Jan., pp. 7–8). Methods of surface finishing for stainless steels are briefly discussed.—R. F. F.

Barrel-Polishing. H. Gros. (Galvano, 1945, vol. 14, Sept., pp. 9–10). The practice of barrel polishing is discussed and standard formulæ for polishing agents are given.—R. F. F.

Barrel Finishing of Metal Products. Part 23. The Progressive Development of Steel Burnishing Materials. H. L. Beaver. (Products Finishing, 1948, vol. 12, July, pp. 60–68).

Polishing—Its Rôle in the Metal Finishing Industry. W. L. Pinner. (Journal of the Electrodepositors' Technical Society, 1948, vol. 23, pp. 95–100). The author deals with polishing as applied to the preparation of steel parts which are to receive a decorative coating of nickel and chromium plate. It is emphasized that as fine a starting polishing grain as possible should be used to avoid coarse polishing scratches. Results are presented of corrosion tests using various sizes of polishing grain on hot-rolled, heat-treated, 1085 motor-car bumper steel. Brief reference is made to automatic polishing equipment and its operation.—J. C. R.

Industrial Electrolytic Polishing. R. Halut and P. Rocquet. (Galvano, 1946, vol. 15, Apr., pp. 8–10). The industrial applications of electrolytic polishing, and the conditions required for successful applications are discussed.—R. F. F.

Rapid Determination of Conditions for Electrolytic Polishing of a Metal. F. Bertein. (Métaux et Corrosion, 1946, vol. 21, Mar., pp. 40–43).

Natural and Substitute Abrasives. H. Gros. (Galvano, 1946, vol. 15, Feb., pp. 6–8). The properties and uses of the more common abrasives (*i.e.*, emery, carborundum, etc.) are briefly surveyed.—R. F. F.

PROTECTIVE COATINGS

Suggestions on the Installation of an Electroplating Shop. (Galvano, 1945, vol. 14, Mar., pp. 7–10; Apr., pp. 9–11; May, pp. 9–11). Four types of automatic or semi-automatic installation are critically discussed as a guide for setting up an electroplating shop.—R. F. F.

Factors Influencing the Quality of Electrolytic Deposits. H. Gros. (Galvano, 1946, vol. 15, Apr., pp. 14–15). The effect of the preparation and nature of the base metal, the current density, and temperature on the quality of deposits are discussed.—R. F. F.

The Passivity of Metals. Its Detrimental Effects in Electroplating. J. Liger. (Galvano, 1946, vol. 15, Mar., pp. 7–9; Apr., pp. 10–12; May; pp. 7–9). Passivity of metals is discussed with special reference to its effect during electroplating. The stages of electroplating when passivity can appear and methods of prevention are described.—R. F. F.

Jet-Test for Determining the Thickness of Lead Coatings. R. A. F. Hammond. (Ministry of Supply, Armament Research Establishment, 1948, Advance Copy: H.M. Stationery Office). The preparation and standardization of a jet-test reagent suitable for determining the local thickness of lead coatings is described. The solution consists of glacial acetic acid, hydrogen peroxide (5% H_2O_2) and distilled water in the proportions 1/1/3 parts by volume respectively.—R. A. R.

Accelerated Exposure Testing of Organic Coatings. A. G. Gray. (Products Finishing, 1948, vol. 12, July, pp. 72–78). Equipment for salt spray, humidity, and colour retention tests on panels with organic coatings is described with recommendations on procedure.—R. A. R.

The Physical Properties of Electrodeposits—Their Determination and Significance. S. Senderoff. (Metal Finishing, 1948, vol. 46, Aug., pp. 48–57). Methods of determining the following properties of metals are described: the tensile strength, hardness, brightness, coefficient of friction, coefficient of linear expansion, internal stresses, electrical resistivity, and density.—R. A. R.

Relationship between the Conditions of Formation and the Shape of Electrolytically Produced Metal Crystals. I. The Formation of Block Structures of Electrolytically Produced Metal Crystals. H. Fischer. (Zeitschrift für Metallkunde, 1948, vol. 39, June, pp. 161–170). The principal difference between electrolytically and non-electrolytically produced metal crystals lies in the much greater thickness range of the layer of growth (10^{-2}–10^{-6} as against 10^{-4}–10^{-5} cm.). The growth of a layer during electrolytic crystallization is demonstrated by models and this is shown to be in agreement with the observed facts.

There are two stages in the formation of a layer. The first consists of the accumulation of atoms one on top of another into a layer until this is stopped by passivation of the atoms on the surface. The metal cations then detach themselves from the edges of the layer, and this continues until the passive surface has again become active, when another layer begins to grow and the cycle is repeated. Many layers can be formed in this manner by the periodic change in the direction of growth.—R. A. R.

Relationship between the Conditions of Formation and the Shape of Electrolytically Produced Metal Crystals. II. The Rôle of Inhibitors in Moderate Inhibition. H. Fischer. (Zeitschrift für Metallkunde, 1948, vol. 39, July, pp. 204–210). It is shown that inhibitors do not cover the most active growing parts during the formation of growing layers in electrolytic crystallization, but inhibit the less active positions of the reactive surface. With increasing inhibition the reactive surface of the growing layer becomes larger whilst the active surface diminishes, *i.e.*, the growing layer spreads and gets thinner.

Interference by inhibitors is all the more probable the more time there is available for them to form a covering layer and the less the competition of the separable cations. When the current is switched off, *i.e.*, when there is no competition from separable cations, the most active areas of growth are irreversibly blocked, provided that the current is off for sufficient time. Polar inhibitors block by specific adsorption preferred areas of higher or lower current density, in accordance with the polarity. In the formation of perfect corners, edges, and surfaces, cation inhibitors preferentially block the corners and edges, and anion inhibitors the surfaces.—R. A. R.

The Operation of a Chromium Plating Bath when Impurities Are Present. (Galvano, 1945, vol. 14, Oct., pp. 11–13, Nov., pp. 12–14; 1946, vol. 15, Feb., pp. 11–12). Methods of operating chromium baths for light plating, when impurities are present are discussed.—R. F. F.

Maintenance of the Chromium Plating Bath. Theoretical Yield and Costing. (Galvano, 1945, vol. 14, July, pp. 9–10). The figures for the concentration and yield of the bath, given in Macchia's book, are critically discussed and alternatives are suggested.—R. F. F.

Hard Chromium. L. Espenotte. (Galvano, 1945, vol. 14, July, pp. 11–14). The different processes for hard chromium plating are discussed.—R. F. F.

Preparation and Finishing of a Chromium Coated Article in The Workshops. E. Gillet. (Galvano, 1945, vol. 14, June, pp. 10–12). The preparation of parts prior to chromium plating and the finishing processes after plating are discussed. R. F. F.

Repairs and Economies. E. Gillet. (Galvano, 1945, vol. 14, May, pp. 12–15). The use of hard chromium coatings for reconditioning worn parts and for simplifying the production of new parts is discussed.—R. F. F.

The Structure of Electrolytic Deposits of Chromium. L. Espenotte. (Galvano, 1945, vol. 14, Apr., pp. 12–13). The work of various investigators is reviewed.—R. F. F.

Applications and Limitations of Hard Chromium Coatings. E. Gillet. (Galvano, 1945, vol. 14, Apr., pp. 13–16). Applications and limitations in the use of hard chromium coatings are discussed.—R. F. F.

Hard Chromium Deposits. J. Liger. (Galvano, 1945, vol. 14, Mar., pp. 11–12). The work of the French investigator Cymboliste on hard chromium deposits is reviewed.—R. F. F.

Porous Chromium Plating. P. Gérard. (Galvano, 1946, vol. 15, Nov., pp. 13–15; 1947, vol. 16, Jan., pp. 13–15). The different manufacturing processes and applications of porous chromium are discussed.—R. F. F.

Advantages of Chromium Plating. (Steel, 1948, vol. 123, Aug. 30, pp. 56–57). The advantages of chromium plating for corrosion elimination and the reduction of friction and wear in various applications are enumerated.—J. P. S.

Chromising Steel Surfaces. G. Black and E. Rosen. (Metal Finishing, 1948, vol. 46, Aug., pp. 70–72). The process of impregnating steel with chromium developed by Becker, Daeves, and Steinberg is described, the information being based on British Intelligence Objectives Sub-Committee Final Report No. 839 (*see* Journ. I. and S.I., 1947, vol. 155, Mar., p. 467).—R. A. R.

Acid or Alkaline Copper Plating Baths? (Galvano, 1946, vol. 15, May, pp. 11–12). The advantages of using an acid or an alkaline bath for copper plating iron and steel before chromium or nickel plating, are compared.—R. F. F.

Impurities in Nickel Plating Baths. H. Gros. (Galvano, 1945, vol. 14, Oct., pp. 10–11; Nov., pp. 11–12). The various kinds of impurities to be found in nickel-plating baths, with methods for removing them are described.—R. F. F.

Lead Impurities in Nickel Plating Baths. (Galvano, 1945, vol. 14, Dec., pp. 10–12). Lead impurities, coming from the piping or the coating of the bath, may prove harmful with plating solutions containing sodium citrate, acetate, or tartrate. A method of removing slight concentrations of lead impurities is given. Previous work on this subject by Raub and Walter is reproduced.—R. F. F.

Peeling of the Coating in the Acid Nickel–Copper–Nickel Plating Process. (Galvano, 1946, vol. 15, Apr., pp. 13–14). Causes and methods of preventing the peeling of the top nickel layer, the top nickel and the copper layers, and of all three layers during plating are discussed.

R. F. F.

Sodium Sulphate Nickel Plating Baths. Pollack. (Galvano, 1947, vol. 16, Jan., pp. 9–11). This is a French translation of an article which appeared in Oberflächentechnik in 1942. The properties of sodium sulphate nickel plating baths are discussed and results of tests with two known electrolytes are given.—R. F. F.

Notes on Modern Nickel and Chromium Plating Practice. N. Christie. (Electrodepositors' Technical Society : Electroplating, 1948, vol. 1, Aug., pp. 495–503). Rules and procedure to be followed in copper, bright and heavy nickel, and chromium plating practice are outlined. An important discussion is included.—J. C. R.

Galvanising without Prior Pickling. (Electroplating, 1948, vol. 1, Sept., pp. 572–573). Two French galvanizing processes are described and the advantages claimed are outlined. The Meitlis process of galvanizing without pickling is applicable only to cold rolled or drawn material in continuous form such as wire and strip between 0·2 and 1 mm. thick. The material, after leaving the rolls or wire-drawing machine, is heated to about 800° C. in an oven filled with cracked ammonia and passed immediately into a bath of molten zinc–aluminium alloy. The Meitlis hot-galvanizing process is the normal hot-dip process of general applicability with certain refinements which result in economy in zinc, fuel, and pickling acids, and an improvement in pot life.—J. C. R.

Notes and Formulae for Alkaline Zinc Plating Baths. (Galvano, 1945, vol. 14, June, p. 9). Improvements to two American formulæ for zinc plating baths are suggested.

R. A. R.

High Production Galvanizing of Small Parts. W. Rudolph. (Metal Finishing, 1948, vol. 62, Sept., pp. 62, 63, 67). A brief description is given of the pickling and galvanizing department of the Buffalo Bolt Company in which about 1500 lb./hr. of bolts and small parts are galvanized. A feature is that each basket of parts coming from the zinc bath is placed in a machine and rotated at 750 r.p.m. to remove surplus zinc.

R. A. R.

Progress of Fluxing in Hot Galvanizing. A. T. Baldwin. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, June, pp. 23, 38). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 229.

Continuous Gas-Radiant Fusion for Electrolytic Tinning. C. E. Cunningham. (Iron and Steel Engineer, 1948, vol. 25, Aug., pp. 85–92). The gas-radiant fusion system for the flowing of tin coatings at the Indiana Harbor plant of the Inland Steel Co., is described and illustrated. The radiant heating panels are mounted on a truck with motor drive for moving the panels to and away from the strip to obtain vernier control of the temperature. A pyrometer is coupled to an electronic potentiometer the impulses of which cause motor-rotation and thus adjust the panel position.—R. E.

Electro-Tinplate in the United States. Its Development and Future Prospects. W. E. Hoare. (Iron and Coal Trades Review, 1948, vol. 157, Oct. 8, pp. 767–776). After briefly sketching the history of the electro-tinplate process in the United States since 1936, the author compares the merits of the acid or " Ferrostan " process, the alkaline process operating on sodium or potassium stannate electrolytes, and the " Halogen " process operating on a stannous fluoride-chloride electrolyte. The corrosion resistance of electro-tinplate is examined and future trends are discussed.—J. C. R.

Evaluation of Strip Plating. R. A. Dimon. (Steel, 1948, vol. 123, Sept. 20, pp. 116–124). As still plating tests do not permit the same current densities as occur in continuous strip tin-plating, test cells have been developed in which the electrolyte flows past the test electrodes at the same speed as the strip travels through the plating tanks. The coatings of test strips are melted and quenched in a similar manner to the commercial practice and reflectivity is measured. From study of the effects of : (1) Rate of solution flow ; (2) current density, (3) electrolyte temperature, (4) tin and glue concentrations, it is concluded that the current density at which the best deposit is obtained is raised by increased strip speed, higher electrolyte temperature, and increased tin concentration, but lowered by increase in glue concentration.—J. P. S.

Full Automatic Cadmium Plating at Friden. J. DeLamar Harrell. (Products Finishing, 1948, vol. 12, July, pp. 20–24). An illustrated description is given of the cadmium-plating department of a company making calculating machines.

R. A. R.

The Chemical Pretreatment of Metals for Painting. R. E. Shaw. (Oil and Colour Trades Journal, 1948, vol. 114, July 2 : Z.D.A. Abstracts, 1948, vol. 6, Aug., p. 119). This general discussion on the chemical pretreatment of metals contains references to iron, zinc, and aluminium. In the case of zinc, whether as sheet or as a galvanized coating, corrosion is best eliminated by the application of a phosphate coating. This method can be applied also to die castings and zinc-plated goods, but does not obviate thorough painting and finishing.

Phosphatization of Metallic Surfaces. M. A. Streicher. (Metal Finishing, 1948, vol. 46, Aug., pp. 61–69). The theory and practice of phosphatizing and its ancillary processes are explained and described.—R. A. R.

A New and Unusual Application of Phosphatizing. H. Gros. (Galvano, 1945, vol. 14, Mar., pp. 15–16) A new application of phosphatizing is found in wire-drawing as replacement for lubricating oils. Washing and drying operations as a protection against corrosion are greatly reduced and the rod, after phosphatizing, can be subjected to up to five drawing passes without any further preparation between passes.—R. F. F.

Theory and Practice of Phosphatizing. H. Jaeger. (Galvano, 1945, vol. 14, Sept., pp. 15–16). The theory and practice of phosphatizing are discussed.—R. F. F.

Properties and Applications of Phosphatizing. H. Jaeger. (Galvano, 1945, vol. 14, Oct., pp. 14–15). The properties and applications of phosphatizing are described.—R. F. F.

Blueing of Iron Ware. G. Joly. (Fonderie, 1947, Nov., p. 893). A short practical note is given of the method used to blue iron-ware.—J. C. R.

Organic Finishes for Metal Products. (Steel, 1948, vol. 122, May 17, pp. 77–82 ; May 31, pp. 56–59, 90 ; June 14, pp. 96–104 ; June 28, pp. 81–84, 100–103 ; vol. 123, July 12, pp. 97–104 ; July 26, pp. 71–73 ; Aug. 9, pp. 83–93 ; Aug. 23, pp. 77–82, 112). This series of eight articles deals with : (1) Gun and electrostatic spray finishing and infra-red backing ; (2) cleaning and preparing the surface for painting, (3) finishes on non-ferrous metals ; (4) synthetic-resin coatings, (5) cellulose coatings and lacquers with a high metal content (6) vinyl-resin coatings and strippable plastic coatings ; (7) methods of testing organic coatings ; and (8) the evaluation of abrasion resistance, heat resistance, and porosity.—R. A. R.

The Protection of Iron by Thermally Produced Oxide Covering Layer (" Thermoxyd " Process). E. Fenner and L. Koch. (Archiv für Metallkunde, 1948, vol. 2, Feb., pp. 53–56). To produce the " thermoxyd " coating the cleaned part is immersed in a bath which produces a surface of suitable thickness and density for the subsequent scaling process of heating for 1 hr. at 750° C. The scale produced has a blue-grey appearance, and good adhesion, and is free from blisters and cracks. The results of tests in running water and a laboratory atmosphere showed good corrosion resistance. The coating is brittle and must not be subjected to impact.—R. A. R.

Functions of Organic Coatings in Present-Day Engineering Problems. J. Mattiello. (Paint and Varnish Production Manager, 1947, vol. 27, pp. 300–304 : British Abstracts, BII, 1948, July, col. 261). The problems involved in coatings for electrical insulation, food and chemical containers, ship bottoms, structural steel, naval aircraft, and railroads are discussed.

Metal Protective Coatings. (Chemical Trade Journal, 1948, vol. 123, July 9, p. 35 : Z.D.A. Abstracts, 1948, vol. 6, Aug., p. 119). An account of the methods used by Schori Metallizing Process, Ltd., for spraying surfaces with plastics or metals is given. The spraying pistol is fed with powdered

material, and it is claimed that a coating can be applied quickly and economically to metallic and non-metallic surfaces. In addition to the usual metals, brittle alloys, unalloyable metals, and even mixtures of metals and non-metals, for example, zinc and plastics, can be easily applied. High temperatures are not developed.

Metallising in Relation to Foundry Practice. J. B. Stiles. (Institute of British Foundrymen, June 8–11, 1948, Paper No. 912). Metallizing is used for two main purposes in the foundry, to apply protective metal coatings and to build up undersize parts or repair defects in them, or modify their size or shape. An account is given of these applications and the operation of modern metallizing equipment. The physical characteristics of sprayed metal are examined.—J. C. R.

Principles and Applications of Metallization by Projection. P. Jacquelin. (Métallurgie, 1948, vol. 80, June, pp. 29–30; July, pp. 22–23). This article deals with the circumstances in which metallization is used, the characteristics of the metal deposited, the method of operation, and the scope for its application.—J. C. R.

Inexpensive Chromated Protein Films. (Chemical Age, 1948, vol. 58, June 19, p. 842: Z.D.A. Abstracts, 1948, vol. 6, Aug., p. 117). An investigation by the U.S. National Bureau of Standards suggests that zinc, iron, brass, and aluminium can be stored safely in mildly corrosive atmospheres. The metallic surfaces are first dipped in casein, albumin, or gelatin; the resultant surfaces are then impregnated with chromate which hardens the film and inhibits corrosion. The chromate solution may be chromic acid, or a dichromate of zinc, iron, or nickel. These films are not injured at 150° C. —an advantage over most chemically produced chromate films.

Progress in the Development of "Low-Temperature" Porcelain Enamels. K. Kautz. (Finish, 1948, vol. 5, No. 2, pp. 25–26, 66: American Ceramic Abstracts, 1948, June 1, p. 124).

Factors Affecting Bubble Formation in Vitreous Enamels. J. A. Clarke. (Institute of Vitreous Enamellers: Sheet Metal Industries, 1948, vol. 25, Aug., pp. 1609–1614). An investigation of bubble formation and the contents of the bubbles in vitreous enamels is reported in which fused ground-coat enamel was examined under the microscope using oblique lighting. In preparing the enamel the addition of only 1% of clay in the mill noticeably increased bubble formation, and this increased with larger clay additions. The decomposition of clay is incomplete when sintering commences. Besides the normal products of combustion, other complex reaction products from the clay content are present in the bubbles. R. A. R.

Infra-Red Drying Stoves. M. Déribéré. (Galvano, 1945, vol. 14, May, pp. 21–23; June, pp. 19–22; July, pp. 19–20). The infra-red lamp installation and drying processes for paints and varnishes are discussed.—R. F. F.

Infra-Red-Radiation Driers in Industry. T. J. J. Manders. (Teknisk Ukeblad, 1948, vol. 95, Oct. 7, pp. 495–503). [In Norwegian]. Industrial applications of infra-red drying are described.—R. A. R.

Organic and Organic-Metallic Toxins Used in Antifouling Paints. H. Rabaté. (Peintures, Pigments-Vernis, 1948, vol. 24, Sept., pp. 275–278). The use of metallic, organic, and metallic-organic toxins in antifouling paints is reviewed.—R. F. F.

Corrosion Inhibiting Primers for Ferrous Metals. W. G. Huckle and H. S. Davidson. (American Paint Journal, 1948, vol. 32, June 28, pp. 76–98: Z.D.A. Abstracts, 1948, vol. 6, Aug., p. 125). Experimental work was undertaken to determine which pigment or pigments, combine most effectively with zinc chromate anti-corrosion primers. Various forms of zinc chromate were tried. The primers were composed of pigments, chromate inhibitors, and vehicles; and the exact composition of each mixture is tabulated. The preparation of the test panels and the results under various conditions are described in comparative tables. The mixture giving the most thorough protection was selected and specified. It was found that in this series of tests basic zinc chromate did not function as an inhibitor in the vehicles employed.

Packaging Superchargers for Shipping and Storage. R. Bruesewitz. (Proceedings of the Association of Iron and Steel Engineers, 1947, pp. 465–472). The preservation of metal parts against corrosion by enclosing them in impervious containers is described.—R. E.

PROPERTIES AND TESTS

New Aids to Research on Strength. K. Rühl. (Die Technik, 1948, vol. 3, July, pp. 301–304). Many instruments for the measurement of stress, elongation, compression, shock loads, and acceleration are described.—R. A. R.

Engineers Seek Uniformity in Nondestructive Testing. D. M. McCutcheon. (SAE Journal, 1948, vol. 56, Sept., pp. 25–26, 40). The activities of, and problems confronting, the Society of Automotive Engineers Iron and Steel Technical Committee which is endeavouring to evolve recommended practices for non-destructive testing are discussed.—R. A. R.

Considerations on the Electrochemistry of Metals. R. Pontielli. (Journal de Chimie Physique, 1948, vol. 45, June, pp. 115–122). The theory of the electrochemical properties of metals are discussed and a bibliography of seventeen references is appended.—R. F. F.

A Description of Some Defects in Steel and Means for Their Detection. H. Thompson. (Sheet Metal Industries, 1948, vol. 25, Sept., pp. 1751–1756). Typical defects in steel are defined and a number of methods of detecting and recording them are briefly described.—R. A. R.

Method of Testing a Metal with the Help of Ring-Shaped Specimens. T. A. Vladimirskii. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 847–857). [In Russian]. A method of tensile testing is described which has been in use in the U.S.S.R. since 1942 for controlling boiler steel. Rings of external diameter from 13 to 34 mm. cut from material 3–16 mm. thick are used, being secured in a special device which enables the tests to be carried out in the normal type of tensile machine. The results obtained for a low carbon steel, which had been subjected to various heat-treatments, are given as examples and compared with those obtained for the same material when the ordinary shape of specimen was employed. Good qualitative agreement between the two sets of results is shown, some of the divergencies being attributed to the somewhat heterogeneous nature of the material. The results are subjected to statistical treatment by the method of regression lines.—S. K.

Determination of the Proof-Stress Limit in Strength Calculations for Tensile Loading. E. Siebel and K. Rühl. (Die Technik, 1948, vol. 3, May, pp. 218–223). A method for the approximate estimation of the proof-stress limit is presented; it is based on the assumption that when the elastic limit is locally exceeded the subsequent deformation increases in proportion to the increase in the purely elastic load.—R. A. R.

Piezoelectric Recording of "Tension-Deformation" Diagrams during Dynamic Tests. Study of Brittleness. P. Bernard. (Mémorial de l'Artillerie Française, 1948, vol. 22, Part 2, pp. 305–322). A method of recording the tension instantly set up in a test-piece in relation to time and measured by piezoelectric quartz has been applied to the impact tensile test. From the results obtained it is shown that brittleness can be influenced by different factors independent of the nature of the materials. At a given temperature brittleness is related to the state of stresses and the speed of loading. The examination of experimental results obtained from these impact tensile tests shows that the combined action of the notch effect acting through the concentration of stresses and the effect of impact, raise the average value of the elastic limit and the breaking load two and a half times. The brittleness of test-pieces appears to be related to the reduced importance of the plastic phase.—J. C. R.

Influence of the Shape of the Testpiece and the Speed of Operation on the Scatter of Results of Tensile Tests on Cast Irons. P. Bastien and L. Beugras. (Fonderie, 1947, Aug., pp. 751–758). Tensile tests were carried out on cast-iron specimens having a threaded head of the Reichsbahn type or an unthreaded cylindrical head, cast at the same time. Results are presented showing the scatter obtained in each case with varying rates of strain. The results are analysed and the scatter is considered to be small and satisfactory when compared with the scatter obtained with static bend and torsion tests.—J. C. R.

Cold Brittleness of Steel under Tensile Stress. D. M. Zagorodskikh. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Jan., pp. 85–88 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, July, p. 20). A series of tests performed on low carbon steel specimens showed that the critical temperature of brittleness in impact bending does not change its

value if specimens are under tensile stress, even close to the yield point, if both sides of the specimen are clamped.

Determination of the Temperature Coefficent of the Modulus of Elasticity of Sheet Material on Bending. A. N. Malinkovich and I. M. Roitman. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 839–842). [In Russian]. An account is given of a method for the measurement of the variation with temperature of the modulus of elasticity of metals and alloys in the form of sheets at from − 50° to + 100° C. Two mirrors are fixed to the specimen, which is held in an oil bath, to constitute an optical lever arrangement for the measurement of the extent to which it bends under the influence of applied loads. The results obtained when specimens 110 × 10 × 0·4–0·6 mm. were subjected to the test at from 20° to 100° C. are given for an alloy (C 0·83%, Ni 35%, Cr 7·9%, W 2·7%, Mn 1·98%, Si 0·18%) and for a steel. The percentage decrease in the modulus of elasticity with this change of temperature was about 0·9% for the former material and about 2·25% for the latter.—S. K.

Apparatus for the Study of the Twisting of Small Samples. P. D. Novokreshchenov and N. E. Markova. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 887–888). [In Russian]. An apparatus in which the turning moment being applied to small specimens is measured with the help of an electrical dynamometer is described.—S. K.

Notch Effect on Transversely Drilled Torsion Bars. G. Seeger. (Die Technik, 1948, vol. 3, July, pp. 309–311).

On the Preparation of Specimens for Testing for Compression. V. B. Shlumper. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 888–889). [In Russian]. An apparatus for the preparation of samples of cast iron for compression tests is briefly described.—S. K.

Measurement of Impact Force with the Help of the Electric Dynamometer. L. D. Sokolov and L. P. Zaitsev. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 843–847). [In Russian]. A method of measuring impact force with the aid of an electrical dynamometer is described, the results obtained with some non-ferrous metals and alloys being given.—S. K.

Present State of Knowledge Relating to Hot Deformation. T. Dahl. (Stahl und Eisen, 1948, vol. 68, Sept. 9, pp. 333–345). The literature on hot deformation, especially rolling, is reviewed under the following headings: (1) The nature of deformation; (2) the beginning of the plastic state; (3) relation between material flow, surface friction, and surface contour; (4) distribution of the reduction in height in upsetting, 'small-area pressing,' rolling, side-pressing of bars, and cross-rolling; (5) distribution of spread across the material in upsetting, 'small-area pressing,' and rolling; (6) conditions for rolling; (7) determination and magnitude of the coefficient of friction in rolling; (8) applying to rolling knowledge of changes in the coefficient of friction; (9) resistance to flow in rolling and the possibility of influencing it; and (10) to what extent is this knowledge now applied to practice.—R. A. R.

Plastic Flow in Anisotropic Sheet Steel. L. R. Jackson, K. F. Smith, and W. T. Lankford. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2440: Metals Technology, 1948, vol. 15, Aug.). In this paper evidence is presented indicating that plastic flow in anisotropic sheet can be described by the shear strain energy flow theory, provided that the anisotropy is properly taken into account. Descriptions of the tensile tests and hydraulic-bulge tests used are given and the data obtained are analysed. The type of anisotropy found in sheet steels is assumed to have orthotropic symmetry, and methods of evaluating this symmetry in terms of two parameters, K_{yz} and K_{xz}, have been developed. It is shown that where these two parameters are used plastic flow of these materials under simple tension and biaxial tension is consistent with the idea that the flow is governed primarily by consideration of shear-strain energy. An appendix deals with effective stress and strain relations for plastic flow in orthotropic sheet materials.—J. C. R.

Statistical Rate Theory of Metals. I. Mechanism of Flow and Application to Tensile Properties. J. W. Fredrickson and H. Eyring. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2423: Metals Technology, 1948, vol. 15, Aug.). A mechanism for the deformation of metals in tension is advanced and applied to experimental data. The proposed model and theory provide an explanation of strain-hardening and the effects of temperature and strain rate on the stress-strain relationship. It does not account for the occurrence of blue brittleness in mild steel, but indicates a change of flow mechanism that was assumed to be an entropy effect occurring in the spring modulus. From the values of the parameters required to fit the data, it is shown that plastic deformation occurs by the movement of rather large domains from one position of equilibrium to another. The free energy of activation and the volume of the domains are shown to be linearly dependent upon temperature. The deformation is shown to be almost entirely an apparent entropy effect with the apparent heat of activation approaching zero.

Experimental Studies of Biaxially Stressed Mild Steel in the Plastic Range. S. J. Fraenkel. (Symposium on Flow and Fracture of Metals: Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 193–200). This paper describes static tests of tubular specimens of 0·23% carbon steel under biaxial stresses at room temperature in order, among other things, to study the absorption of energy as a function of the biaxial stress ratio. A relation between strain energies absorbed under biaxial and uniaxial stress states up to a common maximum strain is tentatively formulated.—R. A. R.

Behaviour of Steel under Biaxial Stress as Determined by Tests on Tubes. H. E. Davis and E. R. Parker. (Symposium on Flow and Fracture of Metals: Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 201–215). This paper describes tests in which 5¼-in. dia. thin-walled low carbon steel tubes were subjected to biaxial stresses at temperatures of 70° F. and − 138° F. The evidence indicates that the metal is reasonably ductile, even at low temperature, provided it is subjected only to a state of plane stress, but if triaxial stresses are induced the ductility may be greatly reduced at the low temperature.—R. A. R.

The Effect of Size and Stored Energy on the Fracture of Tubular Specimens. E. A. Davis. (Symposium on Flow and Fracture of Metals: Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 216–221). Internal pressure tests were made on tubular steel specimens of 0·23% carbon steel of three sizes with wall thicknesses of ¼, ⅛ and $\frac{1}{16}$ in. respectively. In one half of the tests a high-pressure chamber was used to store additional energy in the test system. The size effect as shown by the tests was negligible. The effect of the stored energy was apparent only after fracture actually started.—R. A. R.

Some Properties of a Mechanical Model of Plasticity. H. F. Bohnenblust and P. Duwez. (Symposium on Flow and Fracture of Metals: Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 222–225). Earlier work by the second author on mechanical models demonstrating the plastic deformation of metals is extended in this paper to include the computation of change in potential energy of the metal resulting from work-hardening.—R. A. R.

The Stress-Strain Laws of the Mathematical Theory of Plasticity—A Survey of Recent Progress. W. Prager. (Symposium on Flow and Fracture of Metals: Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 226–233). Typical stress-strain laws of flow and deformation types are discussed, with particular reference to the conditions of continuity and uniqueness which these laws must fulfil if they are to make sense physically—R. A. R.

Stress-Strain Relations for Finite Elastoplastic Deformations. J. E. Dorn and A. J. Latter. (Symposium on Flow and Fracture of Metals: Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 234–236).

A Generalized Deformation Law. E. A. Davis. (Symposium on Flow and Fracture of Metals: Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 237–240). According to Hooke's law the magnitude of infinitesimal elastic strains depends upon two independent constants. In this paper equations are developed which express the magnitude and the distribution of the strains in terms of two independent functions of the stresses; one function is related to the stress-strain diagram and the other is concerned with the distribution of the strains in a state of combined stress. The equations are easily adapted to the relations between the strain rates and the stresses in combined stress-creep tests.—R. A. R.

The General Proof of the Principle of Maximum Plastic Resistance. A. H. Philippidis. (Symposium on Flow and Fracture of Metals: Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 241–242). In this paper the general proof of the principle of maximum plastic resistance of M. Sadowsky is given.—R. A. R.

Discussion of the Forces Acting in Tension Impact Tests of Materials. D. S. Clark and P. E. Duwez. (Symposium on Flow and Fracture of Metals : Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 243–247). A method of measuring the forces acting on a specimen during a tension-impact test (at impact velocities up to 200 ft.lb./sec.) and the computation of force-time relations prevailing in the specimens are described.—R. A. R.

The Propagation of Plasticity in Uniaxial Compression. M. P. White and LeVan Griffis. (Symposium on Flow and Fracture of Metals: Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 256–260). A theoretical investigation of the mechanism of uniaxial compression impact on elastic-plastic materials is described.—R. A. R.

The Interaction of Discontinuity Surfaces in Plastic Fields of Stress. Alice Winzer and G. F. Carrier. (Symposium on Flow and Fracture of Metals : Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 261–264). A fundamental solution for problems associated with discontinuity surfaces in the field of stress has been developed by W. Prager, but its accuracy in certain respects has not been established. In this paper a study is made of the limited case in which the discontinuity surfaces may intersect when they separate fields of constant stress. The results may be applied to more general interesecting fields.—R. A. R.

A Law of Work-Hardening. A. M. Freudenthal and M. Reiner. (Symposium on Flow and Fracture of Metals : Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 265–273). Based on the ' blocking ' theory of the strength of a polycrystalline metal, a law of work-hardening is derived and checked experimentally on mild steel wire deformed by drawing.—R. A. R.

The Influence of the Dimensional Factors on the Mode of Yielding and Fracture in Medium-Carbon Steel. I.—The Geometry and Size of the Flat Tensile Bar. J. Miklowitz. (Symposium on Flow and Fracture of Metals : Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 274–287).

Plastic Deformation of a Circular Diaphragm under Pressure. A. Gleyzal. (Symposium on Flow and Fracture of Metals : Journal of Applied Mechanics, 1948, vol. 15, Sept., pp. 287–296).

Can Castings be Engineered ? F. G. Tatnall. (American Foundrymen's Association, 1948, Preprint No. 48-45). A thin wire strain gauge consisting of 5 in. of copper-nickel wire 0·001-in. in dia. and the technique used with this gauge are described. The application of this gauge to the measurement of residual stresses and to the improvement of casting design are discussed.—R. F. F.

Strain Testing Improves Iron Alloy Machine Parts. H. M. Hardy and T. O. Kuivenen. (Product Engineering, 1948, vol. 19, Aug., pp. 116–120). It is shown how strain-gauge measurements and stress calculations were applied to improve the design of a cast Meehanite crankshaft and compressor cylinder. Strains were also measured in round, square, thick **I** and thin **H** section beams of Meehanite tested transversely.—R. A. R.

Development of Cleavage Fractures in Mild Steels. A. B. Bagsar. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, Oct., pp. 751–809). The susceptibility of several types and thicknesses of mild steel of ship-plate and pressure-vessel qualities and samples of welds to development of cleavage or brittle fractures has been determined by a new test, termed the " cleavage-tear " test, in which a notched tensile-bend type of specimen is used. The effects of notch and test-piece dimensions, load eccentricity, rate of loading, testing temperature, and of heat-treatments were investigated. At temperatures below the transition-temperature range, the presence of a notch of proper shape and orientation was found to create a state of multiaxial stress which appears to expand the elastic range of steel and to raise its proportional limit almost to coincide with its breaking point. The breaking strength of rectangular sections containing a notch of the foregoing type was found to decrease, and susceptibility to cleavage fracture to increase as the notch root radius was decreased. Within the limits investigated, the breaking strength of steel was found to be modified by the notch shape, this modification being practically independent of the size effect if the section was 6 in. or greater in depth. The transition temperatures for the steels investigated in the as-rolled condition were found to be about 100° F. higher than those indicated by the Charpy impact test, and are considered to be more nearly indicative of behaviour of steels in service. Nevertheless, the transition temperature of a steel cannot be defined for service conditions unless the state of stress which prevails under the same conditions is also defined. Two types of fracture were encountered, one being the brittle or cleavage type exhibiting no appreciable deformation and lower nominal breaking strength, and the second the shear type exhibiting normal ductility and higher breaking strength. Fractures above the transition temperature range were of the shear type and below that range of the cleavage type. On the basis of the test data presented, reconsideration of present factors of safety is suggested for monolithic structures with the object of safeguarding against the possibility of development of large cleavage fractures from small discontinuities, notches, or cracks. Other remedial measures for minimizing the damage of cleavage fractures, including modifications in design and material of construction, are suggested. A lengthy discussion is appended.

Method of Detecting Cracks and Surface Defects in Castings. J. Duport. (Fonderie, 1947, Sept., pp. 811–812). A brief description is given of a method for detecting surface defects in which the castings are first immersed in oil at 150–180° for a period varying with their size, and then dipped successively in petrol and methylated spirits. Finally the castings are immersed in a mixture of methylated spirits and powdered chalk. After the castings have dried in the air the defects are indicated by oil seeping from them and staining the chalk coating.—J. C. R.

The Notch Problem with Fluctuating Loads. E. Siebel and K. H. Bussmann. (Die Technik, 1948, vol. 3, June, pp. 249–252). The behaviour of a structural member under fluctuating loads is determined by the load and the derived decrease in strength at the point of maximum load. The member must be designed so that there is sufficient safety margin between the actual stress at the base of the notch and the decrease in strength derived from the fatigue strength. It is shown how the decrease in strength can be determined from bending-fatigue tests on small specimens.—R. A. R.

Shot Quality—How It Affects Fatigue Life. F. P. Zimmerli. (Steel, 1948, vol. 123, Oct. 18, pp. 126–129). Tests of various kinds of steel and cast-iron shot for peening springs to increase the endurance limit have shown that: (1) Within the range tested (25–65, Rockwell C), shot hardness has little effect, and shot size within the range 0·011–0·023 in. has no effect, but coarser shot may " over-peen " the springs; (2) there is no relation between arc height (*i.e.*, the height of the arc into which a test strip bends when peened on one side) and the endurance limit; (3) shot-life is inversely proportional to shot-hardness; and (4) the use of soft shot gives a smoother appearance to the peened surface, which demands an inspection procedure different from the usual.—J. P. S.

Hardness Testing Instruments. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1948, vol. 3, Aug. 31. pp. 269–270). The Poldi and the Ebosa hardness testing instruments are described. The former is a handy tool which can be used on parts which cannot be moved and placed in larger machines. The ball indenter is placed between the test surface and a steel plate of known tensile strength; a suitable holder is provided which is struck a single heavy blow with a hammer and the hardness is obtained from a table by comparing the diameters of the two impressions. The Ebosa instrument makes an impression with a spring-loaded ball or diamond and a comparison is also made using a plate of known hardness.
R. A. R.

A Simple Accurate Microhardness Testing Device. E. B. Bergsman. (Metal Progress, 1948, vol. 54, Aug., pp. 183–188). The apparatus described can be used with any standard inverted miscroscope with only slight modifications necessary to suit various types of stage and objective holder. The indentation is made with a Vickers diamond, fixed in a holder which is interchangeable with the microscope objective. The diamond can be centred in this holder so that the indenter's point can be brought accurately in line with the optical axis of the objective. The applications of the instrument are described.—R. E.

Production Hardness Testing in a Malleable Shop. C. Schneider and L. Ulsenheimer. (American Foundrymen's Association, 1948, Preprint No. 48-25). Two methods of measuring Brinell hardness of pearlitic malleable castings

are discussed. In the first, a load of 3000 kg. is applied on a 10-mm. steel ball and the diameter of the impression measured with a Brinell microscope. In the second, the hardness is determined by means of a direct-reading machine, first by applying a 1500-kg. pre-load and resetting the dial to zero, and then applying the full 3000-kg. load. The operation of this machine, and some labour-saving improvements are described, and the limitations of the method noted.—R. F. F.

The Inspection of Heat-Treated Components. C. M. Medcalf. (Australian Institute of Metals: Australasian Engineer, 1948, July 7, pp. 36–41). Methods of inspecting and testing steel before and after heat-treatment are described; they include deep-etching, hardness tests, measurement of case depth, magnetic sorting bridge testing, and magnetic powder testing.—R. A. R.

Gray Iron Hardenability and Its Relation to Air Quenching of Castings. R. A. Flinn and R. J. Ely. (American Foundrymen's Association, 1948, Preprint No. 48-35). This report discusses first, the range of hardenability available in unalloyed and nickel–molybdenum gray iron, and secondly, the use of hardenability values in planning the quenching of castings. End-quench hardenability and other test specimens with slower cooling rates demonstrate that grey iron follows with good reproducibility the same relationships found in steels even at retarded cooling rates. The hardening of castings by air-quenching to minimize distortion and cracking is then related to these hardenability values and to the surface/volume ratio of the casting. Spot-hardening by flame and induction heating followed by air-cooling is also correlated with the above data.

High-Speed Photographs of Water Jet in the End-Quench Test. (Metal Progress, 1948, vol. 54, Aug., pp. 180–181). The behaviour of a stream of water as it makes contact with a hot steel surface is shown in a series of five stroboscopic photographs, prepared by A. Buchanan, of the initial stages in the end-quenching of a hot steel bar.—R. E.

Formation of Flakes in Steels. V. J. A. Dubovoj. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques, 1946, No. 3, pp. 441–452 [in Russian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 8, p. 1616). Various theories on the formation of flakes are reviewed and the influence of the composition of the steel, and the technique and speed of cooling are noted.

Is there any Connection between Graphitization, Ageing, Snowflakes, Temper-Brittleness? G. Dague and Miss A. Tabarry. (Société Francaise de Métallurgie, May 22, 1947: Revue de Métallurgie, Mémoires, 1948, vol. 45, May–June, pp. 147–159). After the accident at the Springdale power station in the United States in 1943, the cause of which was attributed to the graphitization of steel steam tubing, a co-operative research on a large scale was organized with the object of answering the following questions: (*a*) What are the causes and the mechanism of graphitization? (*b*) What chemical, physical and mechanical influences are factors in graphitization? (*c*) How must the material be checked and controlled before use and in service? (*d*) Is there any means of regenerating the metal? (*e*) What conditions must be observed to avoid graphitization in service? The present authors discuss these question in the first chapter, basing their remarks on the numerous papers in which the American investigations were reported and also on some experiments of their own. In the second chapter they discuss the question whether graphitization cannot serve to explain the development of snowflakes and ageing, and in the last chapter they consider temper brittleness. They draw the following conclusions: (1) Graphitization, like temper brittleness, appears in steels that have passed through the martensite stage, the later rate of cooling determining the predominance of the one or the other phenomenon; (2) graphitization, ageing, snowflakes, and temper brittleness are particularly noticeable in abnormal steels; (3) these four phenomena are a function of the heating below Ac_1 and of the duration of heating at a critical temperature usually situated between 600° and 200° C; (4) they are more marked in fine-grained steels. The authors think they are simply four aspects of the process, namely, the evolution of the $Fe–Fe_3C$ metastable system into the iron–graphite stable system.—A. E. C.

Present-Day Knowledge of the Galvanization Brittleness of Blackheart Malleable Iron. M. Bardot. (Fonderie, 1947, Jan., pp. 487–495). The work of various investigators of the brittleness caused by galvanizing blackheart malleable iron, is summarized. The following conclusions are reached: (1) The risk of brittleness is reduced when the phosphorus content is kept low (under 0·10%) without reducing the silicon content; (2) when the chemical composition of the iron makes it liable to this brittleness the risk may be diminished by either (*a*) heating the iron, after annealing, up to 670° and quenching in water, or (*b*) withdrawing the iron from the annealing furnace at 670° after it had been annealed; (3) either treatment (*a*) or (*b*), but particularly (*a*), increases the service life of iron subjected to low temperature and sudden shock, and also improves its machinability.—J. C. R.

Formation of Cracks in Steel during the Martensite Transformation. E. S. Yakovleva and M. V. Yakutovich. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Jan., pp. 71–74 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, July, p. 34). All cases of formation of cracks during tempering can be explained by one of two schemes. Artificial crack formation according to one of the schemes was produced in small specimens of different carbon contents.

The Influence of Surface Cracks on the Structure-Dependent Properties of Metal Crystals. A. Bichler. (Hutnické Listy, 1948, vol. 3, No. 8, pp. 236–239). [In Czech]. The strength of metals obtained from calculations based on theoretical considerations is about 1000 times the measured value; this paper explains this weakness of metals by theories based on the existence of cracks.—E. G.

Wear Problems. H. Wahl. (Die Technik, 1948, vol. 3, May, pp. 193–204). The whole sphere of wear is reviewed, special attention being given to methods of testing, presenting results of wear tests, and methods of reducing and preventing wear.—R. A. R.

Wear and Wear-Resisting Materials. A. Knickenberg. (Neue Giesserei, 1948, vol. 33–35, Oct., pp. 104–110). All forms of wear to which metals are subjected are reviewed, scaling and corrosion also being regarded as particular forms of wear. The wear-resisting properties of a large number of cast metals and alloys are then discussed.—R. A. R.

The Change in Physical Properties and Structure of Tempered Hypereutectoid Steel as the Basis for Magnetic Methods of Control. Ya. R. Rauzin and Sh. R. Zheleznyakova. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 817–823). [In Russian]. The relation between the magnetic properties of tempered steel (C 1·02%, Cr 1·48%, Mn 0·36%, Si 0·28%) and the magnitudes, nature, and distribution of carbides and the magnitudes of ferrite grains were studied. Specimens 6 mm. in dia. and 215 mm. long were normalized from 980° C., with a rate of cooling ensuring the absence of the carbide lattice. Then, by the appropriate heat-treatment, four types of structures of tempered steel were obtained, *i.e.*, granular pearlite with varying degree of dispersion (ferrite grain-size constant); granular pearlite with the same degree of dispersion and grain-size as above, but with a carbide lattice; granular pearlite with different degree of dispersion and ferrite grain size; and mixed structures of granular and lamellar pearlite. Each structure was photographed at four or five points at a magnification of 2000, and the magnetic properties of all the structures were measured by the ballistic method. Linear relationships were found to exist between magnetic permeability and coercive force on the one hand, and the quantity of carbides in unit volume of granular pearlite on the other: and this relationship persisted even when the distribution of carbides was uneven, including the case of considerable concentrations of carbides along the boundaries of the ferrite grains. The magnetic permeability was decreased and the coercive force was increased by decreasing ferrite grain-size in spheroidized steel, both these characteristics changing on transition to the mixed structures. Structures produced by underheating, containing large amounts of lamellar pearlite without significant changes in grains and growth of carbide particles, have outstanding magnetic properties. Neither permeability nor coercive force was found to represent the carbide lattice. Hardness tests were also carried out and changes in this property were found to occur parallel to changes in coercive force at all stages in the variations of structure occurring in the tempered steel.—S. K.

Some Aspects of the Theory of Iron-Testing by Wattmeter and Bridge. N. F. Astbury. (Journal of the Institution of Electrical Engineers, 1948, vol. 95, Part II, Oct., pp. 607–616). This paper surveys the present position and opens with a

discussion of the limitations of the dynamometer wattmeter. Compensation for voltage circuit phase angle and for eddy current and voltage circuit losses is discussed. The effect of the iron circuits is noted, the influence of the leakage flux being pointed out. The effects of distortion are also noted, and attention is drawn to some hitherto unformulated rules relating the distortion in the current and voltage waves. Null methods of using the wattmeter are briefly described and a new circuit is proposed. The concept of complex permeability is introduced as an approach to bridge measurements, and an equivalent circuit for a test transformer is deduced. It is shown how this may be used in a novel circuit in such a way as to eliminate copper losses. The limitations of the bridge method are briefly discussed, and the relation between bridge and wattmeter methods is shown to lead to the concept of "distortion coefficient," a new characteristic property of the iron, which can be determined experimentally and which may provide a succinct approach to distortion problems.

Determination of Ferrite by the Magnetic Method in the Case of an Incomplete Hardening. L. M. Baldina, M. V. Dekhtjar, and A. M. Gorbunov. (Zavodskaya Laboratoriya, 1946, vol. 12, No. 7–8, pp. 692–700 [in Russian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 8, p. 1618). The method described is based on the magnetic properties of 0·4–1·2% carbon steels and chromium steels. The hysteresis curves for these steels are studied.

Anisotropic Strains Produced by Surface Abrasion, and Their Effect on the Magnetic Properties of Silicon Sheet Steel. R. G. Martindale. (Journal of the Institution of Electrical Engineers, 1948, vol. 95, Part II, Oct., pp. 620–626). Measurements of magnetostriction and permeability of samples of hot and cold-rolled silicon steels are given before and after abrasion in different directions relative to the applied field. It is shown that surface abrasion of electrical sheet steel produces high internal strains of a markedly directional nature, which affect the magnetic properties. The results are interpreted in terms of the domain theory of ferromagnetism.

Polarization Phenomena in Nickel–Iron Alloys, and Their Effective Elimination. O. I. Butler. (Journal of the Institution of Electrical Engineers, 1948, vol. 95, Part II, Oct., pp. 627–635). The distribution of the flux density in ferromagnetic laminæ at various instants is determined. The manner in which the phenomenon of polarization in opposite directions occurs at the outer and inner parts of nickel–iron laminæ is clearly demonstrated for power- and audio-frequency operation. The distribution of harmonic magnetization in the laminæ is determined and is shown to occur in them even when the total flux does not contain harmonics. The calculated results afford an explanation of the difficulties encountered in attempts to demagnetize nickel–iron alloys completely, and assist the development of a reliable method of demagnetization. It is shown that methods that have been applied successfully to silicon–iron alloys, possess inherent defects in the latter case.

Supersonic Inspection. (Welding Engineer, 1948, vol. 33, June, p. 33: [Abstract] Metals Review, 1948, vol. 21, July, p. 26). An account is given of this newly developed testing technique employing high-frequency supersonic waves entering the welded part at an angle. It is a modification of the technique of the Sperry Supersonic Reflectoscope and is known as angle-beam transmission. It can be applied to the inspection of welds in plate, thin sheets, or sections where shape or contour is more or less uniform, and also to inspection of internal defects. It is applicable to both ferrous and light metals.

Influence of the Dimensions of Crystallization on the Propagation of Ultra-Sonic Waves in Metals. P. Bastien, J. Bleton, and E. de Kerverseau. (Comptes Rendus, 1948, vol. 227, Oct. 11, pp. 726–728). In tests on the reflection of ultrasonic waves of 2 mm. wavelength in iron and steel, a number of parasite echoes of various amplitudes that were very mobile on the oscillograph screen were observed when the probe heads were displaced, even only slightly, on the surface of the test-piece; further, the basal echo could not be detected. The loss of energy of a beam of vibrations in direct transmission was extremely great. These anomalies occurred in iron and austenitic 18/8 steel when the average crystal size exceeded 1 mm., and in copper when the size exceeded 0·7 mm.; the ratio 0·7/1 is about the same as 3710/5170, the rates of propagation of the waves in copper and iron. In carbon steel and nickel–chromium–molybdenum steels the anomalies occurred when the dimensions of a complex structure bordered by the edging of pro-eutectoid ferrite which separates during slow cooling in the grain boundaries of the gamma constituent that exists at high temperatures, exceeds 1 mm. These anomalies appear when the cold metal microstructure contains an element of which the average dimension is equal to a multiple of the half-wavelength of the ultrasonic waves in the metal. They are thought to be due to individual vibrations of the crystalline structures which, on account of their dimensions, can resonate with the incident vibration and thus behave as elementary sources of ultrasonic waves.

Method for Shortening the Exposure during the Taking of X-Ray Diffraction Photographs. B. V. Lukin. (Zavodskaya Laboratoriya, 1948, vol. 14, July, p. 883). [In Russian]. A modification of the usual arrangement for X-ray diffraction photography is briefly described, whereby the exposure can be reduced by as much as ten times.—S. K.

Inspection of Metal Castings by Means of Gamma Rays. C. R. Barros and V. L. Ré. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Jan., pp. 36–49).

Electronics in Industry. D. Michell and G. W. West. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy: Australasian Engineer, 1948, July 7, pp. 65–70). *See* Journ. I. and S.I., 1948, vol. 159, July, p. 343.

Contribution to the Study of the Behaviour at High Temperatures of Austenitic and Austenitic-Ferritic Steels Derived from the 18/8 Type. J. Hochmann. (Société Française de Métallurgie, Mar. 11, 1947: Revue de Métallurgie, Mémoires, 1948, vol. 45, May–June, pp. 171–179). At temperatures about 550° C. the mechanical strength of low alloy steels is no longer adequate, and one is led to use steels with greater contents of chromium and nickel, often of the 18/8 type. These, however, are apt to fail by brittle fracture with practically no elongation, and the fracture is nearly always intercrystalline. The author first discusses resistance to creep of 18/8 steels as a function of the carbon content, danger of intercrystalline rupture, and parallelism between the susceptibility to intercrystalline corrosion and to intercrystalline fracture. He then deals with the constitution and hot characteristics of biphase austenitic-ferritic steels. This latter stucture is obtained in iron–nickel–chromium alloys with 20% or 24% of chromium and 8% or 12% of nickel. Carbon, like nickel, causes more austenite to form while elements such as silicon, tungsten, molybdenum, or titanium have the same effect as chromium and promote the appearance of more ferrite. The microstructure consists of a matrix of austenite containing well-defined tiny islands of ferrite. The special properties of these biphase alloys are attributed to the existence of these ferrite islands; if precipitation of chromium carbide should occur it does so on these islands, which are disconnected, and not in the grain boundaries where it would be dangerous because of their continuity.

A. E. C.

Creep of Steel and Concrete in Relation to Prestressed Concrete. G. Magnel. (Journal of the American Concrete Institute, 1948, vol. 19, Feb., pp. 485–500: [Abstract] Metals Review, 1948, vol. 21, July, p. 6). Methods and results are given of creep tests performed on three different samples of steel wire under constant length conditions. Reference is made to the preparation of concrete specimens prestressed by the use of these wires.

Creep of Metals Subjected to Compression Stress. A. H. Sully, G. N. Cale, and G. Willoughby. (Nature, 1948, vol. 162, Sept 11, pp. 411–412). The authors have performed creep tests in compression at constant load on nickel–chromium alloys and find that the three stages discovered in tensile creep tests occur also in compressive creep tests, but whereas the initial decelerating creep rate (primary creep) and the constant creep rate (secondary creep) are approximately the same in value, and occur at the same times in compressive as in tensile tests, the final accelerating rate of creep (tertiary creep) found in tensile creep tests is, in compressive tests, replaced by a stage wherein the creep rate alternately increases and decreases. They ascribe this difference to the fact that, while in tensile tests slip processes occur in the zones adjacent to the grain boundaries leading to misfit at

the boundaries and the formation of fissures at large angles to the applied stress, giving further accelerated creep, the formation of fissures is not as readily possible under compressive stress. Creep therefore may proceed by a series of hardening processes, due to the blocking of dislocations and to recovery processes similar to the onset of recrystallization. These hardening and recovery processes may be localized in material adjacent to the grain boundaries where, owing to flow at the boundaries, the stress concentrations are higher. J. P. S.

Mechanical Properties of Metals and Alloys at Low Temperatures (−196° and −253° C.). Part III. V. I. Kostenetc and A. M. Ivanchenko. (Journal of Technical Physics, U.S.S.R., 1946, vol. 16, No. 6, pp. 539–550 [in Russian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 8, p. 1621). This part deals with 0·1–0·5% carbon steels and with eight Russian low alloy steels.

Low-Temperature Treatment. Sourdillon. (Mémoires de la Société des Ingénieurs Civils de France, 1947, vol. 100, Sept.–Oct., pp. 513–549). A detailed account is given of the effect of low-temperature treatment on the structure and mechanical properties of various plain and alloy steels. A bibliography of thirty-two references is appended.—J. C. R.

Contribution to the Study of the Cementation of Cast Iron by Some Metalloids and Metals. "Dispersed" Cementation. L. F. Girardet and A. Guédras. (Fonderie, 1947, Dec., pp. 970–974). "Dispersed" cementation refers not to a surface transformation of the metal but to a textural transformation caused by metal particles which are not miscible in the iron. In this investigation the authors prepared cylindrical test-pieces with a small cavity bored in them. The cavities were filled with the sulphides and oxides of lead, tin, zinc, and antimony, each with the addition of 1% ammonium chloride; the cavities were sealed and the test-pieces heated in a vacuum furnace. An account is given of the results obtained.—J. C. R.

Influence of Boron on the Structure of High-Speed Steel. A. K. Shevelev. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Jan., pp. 99–104 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, July, p. 10). The addition of boron contributes to the retaining of residual austenite in tempered steel, the amount of which increases with boron content. Furthermore, the addition of boron contributes to the grouping of carbides.

Influence of Boron on the Hardenability of Steels. G. Joly. (Fonderie, 1947, Sept., p. 812). This is a brief note on the effect of very small additions of boron to steel.—J. C. R.

Influence of Chromium on Graphitization of White Cast Iron. G. Joly. (American Foundrymen's Association, 1948, Preprint No. 48-55). The annealing cycles necessary to obtain, with each chromium content which may occur, an iron having a ferritic nodular graphite structure was determined, and the effect of an addition of less than 0·002% boron to the melt studied. Results show that chromium retards graphitization and less than 0·002% of boron does not affect the rate of decomposition of the carbides in the first stage of graphitization. However, boron reduces the time required for the decomposition of pearlite and the diameter of the graphite nodules is reduced and their number increased.—R. F. F.

Solved and Unsolved Problems in the Metallurgy of Blackheart Malleable. H. A. Schwartz. (Institute of British Foundrymen: Foundry Trade Journal, 1948, vol. 84, June 17, pp. 577–584, 586; American Foundryman, 1948, vol. 13, June, pp. 46–54). The hydrogen content of all malleable iron is practically the same, but the mechanical properties of the product seem to bear some systematic relationship to the hydrogen content of the hard iron.

The mechanism by which graphitization is completed with the production of ferrite is very important, but is very difficult to study because it occurs in two stages, the first of which is very rapid, occurring between the A_1 stable and the A_1 metastable temperatures and involving the conversion of austenite into graphite and ferrite. If iron sulphide is present graphitization is retarded, but if manganese is added, graphitization goes on; if tin is now added there is again retardation, and adding a rare earth restores graphitization. Many graphitization accelerators are also deoxidizers and it can be argued that it is the absence of oxygen rather than the presence of these elements that produces the result.

Up to about 0·003% of boron greatly accelerates graphitization without any marked effect upon nodule number. With more than 0·003% the nodule number begins to increase suddenly and enormously. Mixtures of CO and CO_2, but not either gas alone, promote graphitization.—R. A. R.

The Material Cast Iron. E. Piwowarsky. (Neue Giesserei, 1948, vol. 33–35, July, pp. 2–6). Progress made since 1920 in the manufacture of cast iron with improved structure and properties is reviewed.—R. A. R.

Contribution to the Study of High Mechanical Strength Special Cast Irons. G. Delbart and R. Potaszkin. (Fonderie, 1947, June, pp. 673–683). Test-pieces from twelve special cast irons of stated chemical compositions, which were produced in a basic arc furnace, were subjected to various mechanical tests. The results of the tests are detailed and discussed. In most cases calcium silicide was added in the furnace or in the steelworks or foundry ladles. The tests have enabled the influence of carbon and silicon content on mechanical properties and the tendency towards porosity of high-strength special cast irons to be studied. Inoculation with calcium silicide appreciably improved the mechanical properties. Increased porosity was observed when the casting temperature was lower.—J. C. R.

Heating Plates for Electric Cookers. G. Joly. (Fonderie, 1947, Jan., p. 498). A note is presented on suitable compositions for cast-iron heating plates for electric cookers.—J. C. R.

Contribution to the Study of Mechanical Properties of Grey Cast Irons and Improvement of Their Behaviour in Service. A. Collaud. (Fonderie, 1947, Dec., pp. 949–952). The classification of grey cast irons should be made in the light of two different tests: A static test which will indicate its tensile strength and then throw light on the distribution of the graphite, and a dynamic test which will indicate its resistance to shock and thus the ductility of the matrix.—J. P. S.

Mechanical Tests on Grey Cast Irons. J. Praché. (Fonderie, 1948, Apr., pp. 1113–1118). The author discusses the various tests used to determine the mechanical properties of grey cast irons and stresses the fact that variations in these properties are due to speed of cooling and "thickness sensitivity." He concludes that only if large separately cast test-pieces are used and these have been cast in specified conditions, can results obtained with different grey cast irons be classified and compared. The circumstances in which tensile, bend, and shear tests give the most satisfactory indication of the properties required, are outlined.—J. C. R.

Progress in Alloy Steels. H. J. French. (Mining and Metallurgy, 1948, vol. 29, June, pp. 336–340). The author reviews developments in the American alloy steel industry, and shows the increase in the consumption of alloying metals by the steel industry, at the same time indicating their effects in steel. The applications of alloy steels in industry, and their usefulness as compared to carbon steel are discussed. The corrosion rates of 18/8 stainless steel, carbon steel, and copper in certain industrial environments are tabulated.—R. E.

Economy of Material in Metallic Construction. G. Delbart. (Métaux et Corrosion, 1946, vol. 21, May, pp. 64–65, 72). The author discusses the extent to which substitute steels, used during the war in place of chromium–nickel and chromium–molybdenum–nickel steels, can still be satisfactorily used for mechanical construction work.—J. C. R.

Pearlitic Malleable Irons, Plain and Alloyed. R. Schneidewind and D. J. Reese. (American Foundrymen's Association, 1948, Preprint No. 48-49). The authors have investigated the mechanical properties of ferritic and pearlitic malleable irons, plain and alloyed. Particular emphasis was placed upon the relationship between design strength and toughness as measured by the yield point and the elongation respectively. It was found that this relationship might vary widely, but that, with proper heat-treatment, the yield points bore a fixed relationship with elongation. This can be expressed by the equation:

$$Y + 50 \log E = b$$

where Y is the yield point in 1000 lb./sq. in., E is the elongation (%), and b is a constant. This constant equals 95 when the properties meet the A.S.T.M. or Army Ordnance specifications. The average value for the constant obtained in this investigation was 102 which means that, when properly heat-treated, a pearlitic iron should have 7000 lb./sq. in. higher yield point than demanded by specification for any given elongation. Best results were obtained when the

tempering temperature was kept low, about 1200° F. in order that the greatest amount of stress relief and spheroidization might take place with the minimum amount of second-stage graphitization. The temperatures from which the iron was originally either air- or oil-quenched determined the maximum strength obtainable by the heat-treatment. The use of alloys coupled with proper heat-treatment made possible the securing of 5000–10,000 lb./sq. in. greater yield point for a given elongation than was possible with an unalloyed iron. The constant in the above equation averaged 108 for alloyed irons, with some values as high as 115. This improvement was also noted in the case of fully annealed alloy irons. Although oil-quenched irons showed higher maximum yield points than air-quenched irons, after proper heat-treatment the relationship between yield point and elongation was the same. Oil-quenched irons of a given yield strength usually have lower tensile strength than when air-quenched; in other words oil-quenched irons have a higher yield to tensile strength ratio. Where irons are alloyed to permit the production of pearlitic malleable in a cycle designed to produce annealed malleable with plain irons, care must be exercised to use the proper alloys in proper amounts to the particular iron and cycle. There is danger in stabilizing massive carbides with some alloys and of producing primary graphite by inoculation with others.

Methods of Testing Steel Wire Cables for Endurance. D. G. Zhitkov. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 858–867). [In Russian]. The factors on which the endurance of steel cables of various types depends and the principles of machines for the testing of the endurance of such cables are discussed. Details are given of testing machines to function with loads of 3000, 12,000 and 60,000 kg., respectively, and the construction of the replaceable blocks, the means of securing the test cable and dimensions of this latter are dealt with. The results obtained when a steel cable 18·5 mm. in dia. was tested under varying loads and with replaceable blocks of varying diameter, are presented in a three-dimensional diagram in which the ordinate is the endurance, the two abscissæ being the tensile stress and the ratio of the diameters of the block and cable. The relation between the endurance and the number of times a given length of cable has been bent during testing is also shown.—S. K.

Some Factors Affecting Tool Steel Selection. J. M. Pethebridge. (Australian Institute of Metals : Australasian Engineer, 1948, May 7, pp. 34–41). The author endeavours to assess the relative importance of the many factors which affect the selection of tool steels for various jobs.—R. A. R.

Comparative Tool Steel Brands. (Iron Age, 1948, vol. 162, July 29, pp. 79–81). The trade names of tool steels (carbon, die, hot-work, shock-resisting, and high-speed) made by sixteen U.S. firms are listed under the new American Society for Metals classifications.—J. P. S.

Present Day Knowledge of Steels Suitable for Use as Dies When Casting Aluminium Alloys. M. Berdot. (Fonderie, 1947, Oct., pp. 827–842). A review is presented of the published work of various investigators on the choice of cast irons and alloy steels suitable for dies when casting aluminium alloys, and outlining the qualities required and methods of testing. A bibliography of fourteen references is appended.—J. C. R.

Tool and Die Materials, Their Selection, Application, and Heat Treatment. (Steel, 1948, vol. 123, Aug. 16, pp. 98–100, 102, 105, 108; Aug. 23, pp. 82–93; Aug. 30, pp. 65–70; Sept. 6, pp. 96–106, 109; Sept. 13, pp. 106–114; Sept. 27, pp. 92–100; Oct. 4, pp. 84–93). The various applications of tool steels are described, and tables are presented listing the steels of fifty-four makers, according to their applications, with details of their trade names, analysis, and heat-treatment. J. P. S.

Strength Limitations in the Use of SAE 4340 Steel Forgings. E. J. Ripling and L. J. Ebert. (Iron Age, 1948, vol. 162, Aug. 5, pp. 88–93). The use of notched-specimen static-tensile tests to determine the properties of the low alloy steel SAE 4340 indicates that this material in heavy forged form can be used up to stresses of 91·5 tons/sq. in. corresponding to a tempering temperature of 800° F. (420° C). If the absence of stress raisers can be assured, slightly higher stresses are permissible; if stress raisers exist, the maximum stress should be no more than 82·1 tons/sq.in. corresponding to a tempering temperature of 850° F. (495° C.)—J. P. S.

Service Properties of Manganese–Vanadium Plate Steels. F. F. Franklin. (Vancoram Review, 1948, vol. 5, No. 3, pp. 8–9, 21).

Corrosion-Resisting Steels for the Textile Industry. J. A. McWilliam. (Journal of the Textile Institute, 1947, vol. 38, pp. 154–155).

Special Cast Steels for High Strength Service. K. Roesch. (Neue Giesserei, 1948, vol. 33–35, Aug., pp. 39–41). The compositions, and properties obtainable by heat-treatment of low alloy chromium cast steels are reviewed.—R. A. R.

METALLOGRAPHY

A New Microscopic Principle. D. Gabor. (Nature, 1948, vol. 161, May 15, pp. 777–778). The spherical aberration of electron lenses limits the resolving power of the electron microscope to about 5Å, and further improvement is difficult because the resolution limit is proportional to the fourth root of the spherical aberration. A new microscopical principle has been worked out similar to Braggs "X-ray microscope"; it involves an optical synthesis, and is known as the "electron interference microscope." The object is illuminated by a divergent electron beam from a point focus; the primary wave from the source and the coherent part of the secondary wave from the object interfere, falling finally on a photographic plate at a distance which is a multiple of that between the object and the focus. The photograph is developed by reversal, or printed and viewed by transmission, with an optical imitation of the original electron beam.—J. P. S.

The Electron Microscope and Its Metallurgical Applications. P. Grivet, H. Bruck, and F. Bertein. (Métaux et Corrosion, 1946, vol. 21, Jan., pp. 1–10). An illustrated description is given of the electron microscope, the principles underlying its use, and its metallurgical applications.—J. C. R.

Mechanical, Thermal and Optical Instruments Shown at the Physical Society's Exhibition. A. S. Peacock. (Journal of Scientific Instruments, 1948, vol. 25, June, pp. 178–181). Among instruments described are semi-micro-balances, a micro-hardness tester in the form of an attachment to the Vickers projection microscope, an instrument for scanning and recording the readings of twenty thermocouples in six sec., katharometer gas-analysis apparatus, absorptiometers, phase-contrast microscopes, and a new research spectrometer. J. P. S.

Microscopy of High-Temperature Phenomena. H. N. Baumann, jun. (American Ceramic Society Bulletin, 1948, vol. 27, July 15, pp. 267–271). The high-temperature microscope of the Research Laboratory of the Carborundum Company is described, the optical design, new in principle, is shown and its incorporation into a practical thermal microscope detailed. The principles and practice of thermal microscopy, including cinemicrophotography, are described and their applications in ceramic and refractory experimental work indicated.

Photomicrographs of Hot Metal Surfaces. K. W. Keohane. (Iron and Coal Trades Review, 1948, vol. 156, June 18, p. 1296). A brief explanation is given of the principles of the reflecting microscope in which the essential optical components comprising the objectives are mirrors and not the conventional lenses. The instrument is free from chromatic aberration, and it has a long working distance which enables metals at temperatures up to bright red heat to be examined at high magnification. Photomicrographs of molybdenum oxide at red heat at 500 magnifications are shown.—R. A. R.

The Determination of Graphite in Wrought Iron. V. M. Shpeizman and E. V. Elenevskaya. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 879–880). [In Russian]. A procedure for the determination of graphite in wrought iron by the microscopical examination of polished sections and some results obtained thereby are briefly described. S. K.

Photometric Method for Investigating a Surface. N. M. Ziuskin. (Zavodskaya Laboratoriya, 1948, vol. 14, July, pp. 884–886). [In Russian]. A procedure for the photometric investigation of both metallic and porous surfaces is described, and its possible applications are briefly discussed.—S. K.

A Practical Method of Electrolytic Polishing for Steels and Chromium for Micrographic Examination. P. A. Jacquet. (Comptes Rendus, 1948, vol. 227, Sept., 13, pp. 556–558). The difficulties and dangers in the use of the anhydrous solution of perchloric acid and acetic anhydride previously

proposed by Rocquet and Jacquet are avoided with the present solution in which the acetic anhydride is replaced by the acid and only very little perchloric acid is used. A suitable mixture is : 1000 c.c. of pure crystallizable acetic acid and 50 c.c. of 60–65% perchloric acid (sp. gr. 1·59–1·61). The liquids mix at once without liberating heat. The reagent works satisfactorily even when much contaminated with dissolved iron after long use. Best polishing results are obtained with a current density between 12 and 30 amp./sq. dm. with a potential of 30–50 V. for specimens 1–15 sq. cm. in area and a plane cathode 50 sq. cm. in area placed at a distance of a few centimetres in front of the surface to be polished. The relatively high voltage can be reduced by adding a very little distilled water (0·5–1·5%) or by using a cylindrical cathode surrounding the anode. Solutions containing acetic plus perchloric ions attack iron chemically without an applied current, the more so as the temperature rises, so, in order to avoid staining, the specimen is agitated for a few seconds in a dilute aqueous solution of hydrofluoric acid immediately on removal from the polishing bath. This treatment also causes differential colouring, showing up ferrite grains and fine bainitic, sorbitic, and pearlitic structures, as well as the traces of plastic deformation and veining.—A. E. C.

On a Source of Error in the Current/Potential Curve of Electrolytes for Anodic Polishing. Application to the Study of the Mechanism of Polishing. P. A. Jacquet. (Comptes Rendus, 1948, vol. 227, Sept. 20, pp. 591–593). The experiments described show the effect of the microgeometrical features of the surface of the anode on the current/potential curve in an electrolytic polishing bath. The solution consisted of 765 c.c. of acetic anhydride, 185 c.c. of 63% perchloric acid, and 50 c.c. of water at 20° C. ; the specimens were of 0·22% carbon steel as cast, and the surfaces were either ground on emery paper and emery dust or were polished electrolytically. On raising the potential the current rose to a well-defined maximum followed by a minimum in the neighbourhood of 15 V. with the emery-ground specimen, but for the polished specimen it rose gently without a maximum. The author uses these facts to explain the mechanism of electrolytic polishing. It is known that the anode is surrounded by a badly conducting viscous layer of solution rich in products of solution. In the early stages this layer forms in the " valleys " and the " hills " emerge through it, so that the current is concentrated on the hills, which are thus dissolved away preferentially.—A. E. C.

A Method for Rapid Electrolytic Polishing. L. Chamagne, H. Granjon, and A. Leroy. (Métaux et Corrosion, 1946, vol. 21, June, pp. 73–80). A method is described which enables specimens to be electrolytically polished in 15 sec. instead of the usual 8 min.—J. C. R.

Grains, Phases and Interfaces : An Interpretation of Microstructure. C. S. Smith. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2387 : Metals Technology, 1948, vol. 15, June). The author develops the simple concept that many microstructures are the result of an attempted approach to equilibrium between phase and grain interfaces, the surface tensions of which balance each other geometrically at the points and along the lines where they meet. The discussion is limited to structures obtained after full annealing. Micrographs of many alloys are studied to show the influence of surface tension and other factors on the shape of grains and grain boundary constituents. R. A. R.

The Maurer Diagram and Its Evolution and a New Structural Diagram for Cast Iron. H. Laplanche. (Institute of British Foundrymen, June 8–11, 1948, Paper No. 901). The various micrographic structures of cast irons are outlined and their influence on mechanical properties is reviewed. When considering the choice of a cast iron for a given purpose the structure is first determined and then the composition is formulated to give this structure. To facilitate this, various investigators have drawn diagrams relating structure to composition. The author critically surveys Maurer's diagrams and those of Greiner and Klingenstein, Coyle, Norbury, Uhlitzsch and Weichelt, and Schwarz and Vath. He describes his own work on the structure of iron–carbon–silicon alloys and gives his own structural diagram for cast iron.—J. C. R.

On the Structure of the High Temperature Metals. R. Franks. (Yearbook of the American Iron and Steel Institute, 1948, pp. 459–474). The microstructure of iron-base, nickel-base, and cobalt-base alloys used in the construction of jet engines and gas turbines is considered. The structures are austenitic in character and contain precipitated compounds, presumably representing carbides and nitrides of chromium, molybdenum, tungsten, columbium, and titanium. These compounds are randomly distributed, particularly if the alloys are heated in the 1200–1500° F. range. The presence of these compounds lowers the ductility and increases the strength at high temperatures, the effect being most marked in alloys with large grains. If both grain-size and mode of precipitation of these compounds could be simultaneously controlled, this would probably be a means of producing a very stable structure which would retain its mechanical properties at high temperatures. It is suggested that ferritic alloys for the same applications might be produced by proper control of the grain-size and precipitation.—R. A. R.

Contribution to the Study of the Morphology of Nonmetallic Inclusions in Ferrous Materials. Inclusions in Commercial Pure Iron. R. Zoja. (Metallurgia Italiana, 1947, vol. 39, Nov.–Dec., pp. 267–280 : [Abstract] Metals Review, 1948, vol. 21, July, p. 10). Results are given of an investigation of 99·9% iron, produced on a semi-commercial scale, with regard to the frequency, distribution, and grouping of different types of non-metallic inclusions. Electrolytic, Armco, and " Ferrital " irons were also investigated.

As-Cast Structures in Cast Steels. M. F. Hawkes and B. F. Brown. (Iron Age, 1948, vol. 162, Oct. 14, pp. 138–147). The authors explain the origin of dendritic structures in cast steel and the modifications which occur in cooling and in heat-treatment. The effect of phosphorus in determining the growth of ferrite, and therefore affecting carbon diffusion, is also taken into account.—J. P. S.

Applied X-Ray Metallography. N. P. Goss. (Steel, 1948, vol. 123, July 5, pp. 98, 101, 102 ; Sept. 6, pp. 114–117, 132–139). The first of this series of articles deals with the general application of X-ray diffraction to the crystalline structure of metals ; types of space lattice are discussed in the second, the Miller system of indices is described, and the calculation of lattice parameters outlined. The reasons for the diffraction of X-rays by the regularly arranged atoms of a space lattice are shown.—J. P. S.

Technique and Applications of Back-Reflection Diagrams in X-Ray Crystallography. J. Bénard. (Métaux et Corrosion, 1946, vol. 21, Mar., pp. 33–40).

Steel Hardening as the Radiologist Sees It. P. Skulari. (Hutnické Listy, 1948, vol. 3, No. 7, pp. 197–200 ; No. 8, pp. 231–233). [In Czech]. This paper explains the theories on the mechanism of the hardening process. The various iron phases and their respective space lattices are described and the values for the different lattice parameters are given. According to the author the problems of steel hardening are closely connected with the nature and structure of the martensite. From the point of view of the radiologist the assumption that martensite is a solid solution of carbon in ferrite is acceptable, because no traces of cementite are ever detected in martensite, furthermore, its properties indicate that this view is likely to be correct.—E. G.

X-Ray Study of the Superficial Straining of Single Crystals of Aluminium and Iron by Mechanical Polishing. J. Bénard and P. Lacombe. (Académie des Sciences, Jan. 14, 1946 : Métaux et Corrosion, 1946, vol. 21, Feb., pp. 30–31). The authors describe their X-ray examinations and state that results enable the depth of disturbance of the crystal due to abrasion to be determined and the mechanism of the progressive transformation of a single crystal into irregular clusters of crystallites to be analysed.—J. C. R.

Advancements in the Isolation of Inclusions and Structural Components in Alloyed and Unalloyed Steels. P. Klinger and W. Koch. (Stahl und Eisen, 1948, vol. 68, Sept. 9, pp. 321–333). A number of processes for isolating oxide inclusions and the electrolytic method of isolating carbides in alloyed and unalloyed steels are described. The inclusions from several steels have been examined under the light microscope and in the electron microscope, and their formation and behaviour during the deformation of steel are discussed. There are thirty-two reproductions of inclusions at high magnification R. A. R

The Formation of Crystals of Spectroscopically Pure Iron D. L. Phillips. (Research, 1948, vol. 1, July, pp. 479–480

When mild steel rods were heated for four days at 1000° C. in sealed evacuated silica sheaths, crystalline deposits formed on the ends and sometimes along the upper surface of the rods. X-ray examination showed that they were polycrystalline aggregates of α-iron. Similar crystals were formed in the range of vacuum from 10^{-3} to 30 mm. pressure when the residual gas was air, argon, nitrogen, hydrogen, or carbon monoxide. The rods used were forged and cold drawn to 0·44 cm. in dia. and the silica sheaths were 0·48 cm. in internal dia. When the distance between the rod and the sheath was increased above a critical amount no crystals were formed; similarly, crystals did not form at the ends of a short piece of rod in the same tube when the gap between the ends exceeded a certain distance.—R. A. R.

Transient Nucleation. D. Turnbull. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2365: Metals Technology, 1948, vol. 15, June). The assumption of M. Volmer and R. Becker that a steady-state condition exists such that the concentrations of embryos of subcritical size do not change with time is probably justified for the formation of liquid embryos in supersaturated vapours, but is open to criticism when applied to transformations within condensed phases. The author finds that in condensed systems there is an incubation period in which no nuclei appear to form, but thereafter the rate of nucleation increases with time. The incubation period arises from comparatively slow rates of diffusion in condensed systems and the consequent slow approach to steady-state nucleation. This explains the acceleration of nucleation with time observed by Mehl for the decomposition of austenite into pearlite.—R. A. R.

Nucleation of Phase Transformations. J. C. Fisher, J. H. Hollomon, and D. Turnbull. (American Institute of Mining and Metallurgical Engineers, Technical Note No. 5: Metals Technology, 1948, vol. 15, Aug.). A brief description is given of transient nucleation processes which should enable all phase transformations to be described satisfactorily in terms of nucleation and growth.—J. C. R.

The T.T.T. Diagram. F. van Wijk. (Metalen, 1948, vol. 2, Aug., pp. 253–258). [In Dutch]. The isothermal transformation of austenite and the application of transformation–temperature–time diagrams are discussed. It is supposed that bainite is formed by a lattice shearing process after the carbon atoms have been arranged in the austenite lattice in such a way as to make the shearing possible. The effects of the common alloying elements on the isothermal transformation are referred to.—R. A. R.

Transformations in Iron. (Iron and Coal Trades Review, 1948, vol. 157, July 16, pp. 137–138). This is a summary of a colloquium at the British Iron and Steel Research Association at which J. Savage discussed "The Geometrical Aspects and Mechanism of Transformations in Iron." Several theories of the mechanism of the $\gamma \rightarrow \alpha$ transformation were reviewed and it was shown that the Bain hypothesis of a "concertina-like" shear of a body-centred tetragonal structure, equivalent to the face-centred cube, to produce a body-centred cubic lattice was unlikely, as it involved major local disturbances of atomic positions. It was demonstrated that if the 110 planes of a face-centred cubic lattice of iron were sheared at 19° 28′, a structure that was nearly body-centred cubic would be obtained, the original 110 planes of the γ-iron becoming the 211 planes of α-iron. Other possibilities of shear and the effects of elastic and plastic deformation were discussed.—R. A. R.

Alloys Isomorphous with the Iron–Chromium Sigma Phase. K. W. Andrews. (Research, 1948, vol. 1, July, pp. 478–479). A. H. Sully and T. J. Heal have referred to the existence of a phase in the cobalt–chromium system isomorphous with the iron–chromium sigma phase, and F. Wever and J. W. Jellinghaus to a third isomorphous phase in the iron–vanadium system. These three isomorphous phases appear to be based on the equiatomic compositions represented by Fe–Cr, Co–Cr, and Fe–V. This fact might suggest that the formation of these sigma phases depends on the onset of an ordered structure which immediately undergoes some kind of distortion; evidence supporting this is given. The existence of unsymmetrical rather than spherical ions as has been suggested for α-manganese may also be a feature of the sigma alloys.—R. A. R.

Influence of Manganese on Polymorphic Transformations in Chromium Steels. A. T. Grigoriev and D. L. Kudriavcev. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Chimiques, 1947, No. 4, pp. 329–336). [In Russian].

CORROSION

The Thermodynamic Bases of the Theory of Corrosion. M. Pourbaix. (Métaux et Corrosion, 1946, vol. 21, Oct.–Nov., pp. 121–129). The application of thermodynamics to the study of corrosion of iron by aqueous solutions is reviewed. J. C. R.

Corrosion Research in England and the United States during the War (1940–1945). E. Herzog. (Métaux et Corrosion, 1946, vol. 21, July, pp. 92–100; Dec., pp. 137–149; 1947, vol. 22, Oct., pp. 168–175). A survey is presented of the research work carried out during the war years in Britain and the United States on the corrosion of iron and steel and its prevention.—J. C. R.

Progress Being Made in Fight against Corrosion Losses of Metals. W. Mann. (Materials and Methods, 1948, vol. 28, Aug., pp. 51–55). The theory of corrosion is briefly explained and some methods of combating it are described.—R. A. R.

Comparison of O.T.U.A. Long Term Corrosion Tests with Rapid Laboratory Tests. G. Chaudron. (Métaux et Corrosion, 1946, vol. 21, Feb., pp. 21–24). In this first part an account is given of the various types of steel used in the long-term tests of the Office Technique pour Utilisation d'Acier with details of the places where the plates were exposed to the air or in fresh or sea water, and brief notes on the results observed after five years.—J. C. R.

Basic Principles of Corrosion Control by the Use of Lime. E. S. Hopkins. (Paper Trade Journal, 1948, vol. 127, July 1, pp. 61–63: [Abstract] Metals Review, 1948, vol. 21, Aug., p. 18). Principles of corrosion of iron and steel water pipe as a function of the dissolved oxygen, are enumerated. Neutralization of free carbon dioxide in low alkaline waters by lime and the subsequent precipitation of a calcium-carbonate/ferric-oxide coating on pipe surfaces retards corrosion to the point of practical elimination.

Studies Factors Affecting Stabilization of Stainless Steels. (Steel, 1948, vol. 123, Sept. 6, p. 119). Experiments carried out by the National Bureau of Standards, Washington, on the effect of titanium and niobium in producing stabilization of the carbides in 18/8 stainless steel, involved a sensitizing treatment for varying times at 840–1380° F. (450°–750° C.) before exposure to boiling acidified copper sulphate solution. It is concluded that, for substantially complete immunity to intergranular corrosion, a minimum ratio of niobium to carbon of 10 : 1, and of titanium to carbon of 5 : 1, is required. Niobium-treated steels require no stabilizing heat-treatment but titanium-treated steels are improved by heat-treatment. J. P. S.

Accelerated Corrosion Testing of Protective and Decorative Coatings. R. R. Rogers. (Canadian Chemistry and Process Industries, 1946, vol. 30, Oct., pp. 91–94). The accelerated corrosion test must conform to the normal service conditions of the material under test. The apparatus installed at the corrosion testing laboratories of the Canadian Bureau of Mines is described.

Corrosion of Metals with Oxygen Depolarization. N. D. Tomashoff. (Light Metals, 1947, vol. 10, Dec., pp. 637–645; 1948, vol. 11, Jan., pp. 8–14; Feb., pp. 104–112; Mar., pp. 155–160; July, pp. 388–396; Sept., pp. 503–509). This series of articles constitutes an English summary of the author's book with the same title, published in Moscow in 1947, in which he presents the results of systematic experimental work at Professor Akimoff's Laboratory, Institute of Aircraft Materials, and at the Colloido-Electrochemical Institute of the Russian Academy of Sciences.

In addition to a theoretical analysis of general problems of electrochemical corrosion, an exhaustive treatment is made of the corrosion processes that occur with oxygen depolarization.—R. A. R.

Researches on the Corrosion of Cast Iron by Aluminium and Light Alloys Containing Silicon. (Alpax and Molten High-Silicon Aluminium–Silicon Alloys). P. Bastien and Suzanne Daeschner. (Fonderie, 1947, Dec., pp. 962–965). The authors describe experiments made with different cast irons to determine which resisted best the attack of molten aluminium and light alloys. The extent of corrosion was measured by the loss of weight of the specimen or by determination of the iron dissolved by the molten alloy. Results showed that, except in the case of malleable iron, attack by Alpac and a high silicon (15·92%) aluminium–silicon alloy was more pronounced than attack by unalloyed alumin-

ium. Additions of molybdenum and chromium to the iron did not improve resistance to attack. A note is included on the mechanism of the attack.—J. C. R.

Study of the Corrosion of Cast Iron Crucibles Used for the Melting of Light Alloys. M. Bardot. (Fonderie, 1947, Sept., pp. 798–810). A review is presented of the work of various investigators on the action of molten aluminium on cast irons, the respective advantages of cast iron and graphite crucibles when melting light alloys, and the use of coatings for the inside of the cast-iron crucibles to restrict attack. A bibliography of seventeen references is appended.—J. C. R.

Steel Cables—Their Inspection. J. G. Haenel. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Jan., pp. 99–111). The author discusses types of corrosion which may attack steel cables and methods for their prevention.

Corrosion-Resistant Steel Castings for the Chemical and Food Industries. H. Hubscher. (Chimia, 1948, vol. 2, Apr. 10, pp. 78–82 : [Abstract] Metals Review, 1948, vol. 21, Aug., p. 34). Production and properties of martensitic, ferritic, and austenitic stainless steels are discussed. Three methods are given for preventing intercrystalline corrosion and the resulting electrolytic action of the carbides on the grains.

Marine Corrosion Testing. F. N. Speller. (Blast Furnace and Steel Plant, 1948, vol. 36, Aug., pp. 950–953). The activities of the Kure Beach corrosion-testing establishment, operated jointly by the International Nickel Company and the Dow Chemical Company, are briefly described. The good resistance of low alloy steels to sea-water exposure is noted.—J. P. S.

Cathodic Protection of Casings in London Pool. S. P. Euring and J. F. Bayhi. (Corrosion, 1948, vol. 4, June, pp. 264–286). The tests carried out to determine the most economical and feasible method of applying cathodic protection to the insulated casings at London Pool, are described. Results of short-time applications of protective current to wells at the London Pool, show that casings 1500 ft. long can be protected by a current of from 1·0–1·5 amp. and on Devonian wells cased to approximately 3000 ft., the protection appears to extend to about 2000 ft.—R. F. F.

Cathodic Protection of Steel Underground Structures Demonstrated by Tests. (Civil Engineering (U.S.A.), 1948, vol. 18, Aug., p. 45 : Railway Engineering Abstracts, 1948, vol. 3, Oct., p. 258). Tests carried out by the National Bureau of Standards in America have demonstrated that a cathodic unit can economically be used to protect steel pipe lines from corrosion. Where pipe lines are in corrosive soils and there is no source of electric power, it was found that the galvanic corrosion of bars of electronegative metals buried at intervals and connected to the pipe line provided a source of energy for cathodic protection. Results of field tests are given and illustrations show the effectiveness of such protection.

Methods of Decreasing the Corrosion of Underground Pipes. O. Scarpa. (Metallurgia Italiana, 1947, vol. 39, Nov–Dec., pp. 261–266 : [Abstract] Metals Review, 1948, vol. 21, July, p. 14). Results of an investigation show the effects of currents leaking from electric railway lines. The use of a special coating for the pipes is recommended.

Preventing Galvanic Corrosion. H. Seymour. (Mining Magazine, 1948, vol. 79, Aug., pp. 84–87). The principles of cathodic protection are explained and examples of its application to buried pipe lines are cited.—R. A. R.

Corrosion. Its Effect in Boiler Systems. Part I. R. L. Reed. (Combustion, 1948, vol. 19, No. 11, pp. 28–33 : Chemical Abstracts, 1948, vol. 42, Aug. 20, col. 6027). A discussion is presented of theories of corrosion, the action of oxygen in the boiler system, its removal by chemical and mechanical means, and protection against its action in idle boilers.

Corrosion : Its Effect in Boiler Systems. Part II. R. L. Reed. (Combustion, 1948, vol. 19, June, pp. 93–94).

Corrosion of Boiler Plates. Scohy. (Exp. Nat. Ind. Chim. Charleroi, 1945, pp. 45–53 : British Abstracts, 1948, BI, Aug., col. 412). The results of short-time corrosion tests on steel in contact with water of various *p*H values and salt, oxygen, and carbon dioxide contents are described. The onset of corrosion is delayed with increase in *p*H, and corrosion becomes negligible at *p*H 12. In absence of NaCl, neutral salts increase corrosion when this is slight, but when it is considerable and the *p*H is < 10 they have only a small effect. For *p*H < 6, corrosion decreases with decrease in *p*H. In presence of dissolved oxygen minimum corrosion occurs in water (*p*H 6·25) containing 0·05–0·10 mg. of oxygen per litre. Methods of reducing the corrosive action of boiler water by maintaining a high *p*H and the influence of ions resulting from water-softening treatments are discussed. All traces of oxygen must be eliminated since corrosion is increased in presence of oxygen, especially at high pressures, and, where complete removal by boiling is impossible, it may be necessary to add reducing agents, *e.g.*, Na_2SO_3.

Some Corrosion Experiences in a Power Station. F. Scott and E. W. Gilham. (Electrical Power Engineers' Association : Steam Engineer, 1948, vol. 17, Sept., pp. 447–451). The corrosion of desuperheaters and boiler feed pumps at high temperatures is discussed with descriptions of practical examples.—R. A. R.

ECONOMICS AND STATISTICS

Development of the French Steel Industry. (Echo des Mines, 1948, Sept., pp. 171–172). The organization of the steel industry in France is discussed.—R. F. F.

An "Intermediate" Balance Sheet of German Foundries. H. Burkart. (Neue Giesserei, 1948, vol. 33–35, July, pp. 8–11). An attempt is made to give an overall picture of the present position of the German foundry industry by reviewing statistics relating to 1425 iron, malleable iron, and steel foundries.—R. A. R.

Increasing Production. F. Pristl. (Neue Giesserei, 1948, vol. 33–35, Oct., pp. 120–121). Improvements in administration and economic measures for increasing production under present-day conditions in Germany are discussed.—R. A. R.

Planning of the Austrian Iron and Steel Industry. (Hutnické Listy, 1948, vol. 3, No. 8, pp. 245–246). [In Czech]. The Austrian steel industry has grown considerably during the war, but many of the wartime projects remained uncompleted, the industry does not therefore present an organically built-up structure. Sufficient home-produced ore is available, but its iron content is very low and production is expensive. It is planned to increase the ore mining sucessively from the present figure of 1,230,000 tons/annum to 2,535,000 tons in 1958. The pig-iron production is to be increased from 278,000 tons in 1947 (389,000 tons in 1937) to 797,000 tons/annum, of which 752,000 tons are to be used for steel production and 45,000 for foundry work and for hematite. In addition the production of 7200 tons/annum of special foundry pig iron in Sulzan-Werken will be continued. The annual production of steel ingots is to be increased to 1,070,500 tons of which 181,500 tons are to be produced in electric furnaces, and 889,000 tons by the open-hearth and converter processes. For this 733,125 tons of pig iron and 396,300 tons of steel scrap will be required. The estimated current consumption of the whole iron and steel industry is 1,890 million kWh./annum, of which 366 million will be produced by the industry itself and the balance will have to be purchased.—E. G.

The Iron Foundries' Scrap Problem. I. Hurtig. (Gjuteriet, 1948, vol. 38, June–July, pp. 93–100). [In Swedish]. The author discusses the international scrap trade in 1938, scrap collection, import and export of scrap in Sweden, and forecasts a deficiency of 30,000 tons in Sweden for 1948. Measures to meet the situation are suggested.—R. A. R.

Sweden's Iron and Steel Exports. S. L. Wahlström. (Jernkontorets Annaler, 1948, vol. 132, No. 9, pp. 275–314). [In Swedish]. Sweden's export trade in iron and steel is discussed and data on their distribution and value are presented in nine tables.—R. A. R.

Do You Use Your Cost System? R. L. Lee. (Institute of British Foundrymen, June 8–11, 1948, Paper No. 911). The author emphasizes the importance of operating a costing system which enables current operations to be judged and results to be accurately forecast. Specimen forms that can be used by the different departments are illustrated, and particular reference is made to wages-office procedure.—J. C. R.

Foundry Costs and Cost Controls. C. E. Westover. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 326–331). *See* Journ. I. and S.I., 1948, vol. 159, June, p. 219.

Steelworks Cost and Profit Calculations. F. Kling. (Jernkontorets Annaler, 1948, vol. 132, No. 8, pp. 243–270). [In Swedish]. Definitions are first given of some of the costing and accounting terms used in the paper. The particular difficulties of steelworks costing are touched on and rapid

methods are given for (*a*) evaluating the scrap arising during production and (*b*) calculating coefficients representing the extra cost per kilogram of added alloying element per 1000 kg. of carbon steel at different stages of production, *i.e.*, as ingots, billets, and finished products. It is shown that, for internal debiting, products can be divided into "natural" groups (such as pig iron, finished hot-rolled, cold-rolled, and fabricated); these should be charged by one department to another at market price, but the internal debiting by departments covering successive stages of production should be at actual cost price. Standard cost accounting and the preparation of monthly statements of profit and loss are explained. A detailed description is then given of a method of analysing costs and profits with special reference to marginal cost and marginal profit; specimen diagrams for this purpose are shown and from these it is seen that the object should be to obtain the economic optimum for the whole undertaking, rather than the maximum profit on each product.

In the selection of orders, calculations should be based on some kind of time unit rather than per ton. The author suggests profit evaluation in relation to that part of the total production costs which is directly proportional to time. Finally, costing for orders for small quantities is dealt with. R. A. R.

The Cost of Power for an Integrated Iron and Steel Works and Its Allocation to the Products. K. Rummel. (Stahl und Eisen, 1948, vol. 68, Aug. 12, pp. 294–301). It is shown how to present energy balance sheets for an integrated iron and steel works, one on the basis of calories and a second on the basis of cost. An example is then given of the application of the method to consumption and production data relating to one month's operations by a German steelworks.—R. A. R.

Job Evaluation System is Easily Installed. M. E. Annich. (American Foundryman, 1948, vol. 13, May, pp. 84–87). A system of "job-evaluation," as a basis for rates of pay, has been based on the following considerations—the education, experience and skill required of the worker, the responsibility for equipment, product, and risk to other operatives incurred in performing the job, and the working conditions, physical exertion, mental or nervous demand, and accident risk necessarily associated with it. Each of these factors is assessed on a scale with a range of from 10 to a maximum of, *e.g.*, 30, in the requirement of experience, and 15 in the case of working conditions. Each job therefore receives a rating in the range 100 to 160, and rates of pay derived from this are added to the minimum or "common labour" rate.—J. P. S.

Establishment and Use of Standard Data-Timestudy Techniques. M. E. Annich. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 221–240). This paper presents some fundamentals for making time-studies in moulding and for correctly interpreting time-study data. The various time-study elements are defined and discussed, actual test data being used in the examples. The logical method for establishing standards is by formula derived from analysis of enough time-studies on any one operation to cover all of the variations on elements normally encountered.

BOOK NOTICE

WERNICK, S. "*Electrolytic Polishing and Bright Plating of Metals.*" 8vo, pp. xv + 243. Illustrated. London, 1948: Alvin Redman, Ltd. (Price 30*s.*).

This is a book that was really needed, and it meets the need in a very satisfactory way.

Appearance is unquestionably an important factor in the design of most things, and as far as metal wares are concerned, nothing is more attractive to most potential users than a surface that shines with a lasting glitter. The production of this type of surface, even when it is a plated one, generally involves polishing operations, which are normally carried out by expensive and laborious mechanical methods. In some cases, recently developed processes of electrolytic polishing can largely replace mechanical polishing, and save some time and a great deal of labour; bright-plating can save time and labour too.

The author is an acknowledged authority on these two closely related subjects, and all those who are interested in metal finishing should be grateful to him for compiling this account of the progress that has been made in bringing the processes to their present stage of development.

The book deals mainly with the practical aspects of the problems and the industrial applications, established and potential, of the processes. The theoretical aspects are not ignored, but some readers may find the treatment of this side of the subject rather disappointing, and others would have appreciated a fuller account of the metallographic applications of electrolytic polishing.

There are six chapters on the electrolytic polishing of nickel, aluminium, copper, silver, brass, carbon steel, and stainless steel, respectively, and six chapters dealing with the bright-plating of nickel, zinc, cadmium, copper, silver, and the platinum metals, respectively. Chromium plating is mentioned at various points in the text, but the author apparently considered it to be outside the scope of his book. A chapter dealing specifically with this metal would probably be welcomed by most readers.

Particulars are given in the relevant chapters of various modifications of the processes, as applied to the different metals. It may seem that too many alternative processes are described, but the subject is still a young one, in the active developing stage, and the author has treated it as critically as he felt justified in doing, without having had the opportunity of trying out all the different modifications.

The book concludes with an annotated bibliography covering more than 300 references to bright-plating, and more than 200 to electrolytic polishing.—M. S. FISHER.

NEW PUBLICATIONS

BIKERMAN, J. J. "*Surface Chemistry for Industrial Research.*" 8vo, pp. ix + 464. Illustrated. New York, 1948: Academic Press Inc. (Price 44*s.*).

CHAMBRE SYNDICALE DES PRODUCTEURS D'ACIERS FINS ET SPÉCIAUX. "*Les Aciers Fins et Spéciaux Français.*" 8vo, pp. 301. Illustrated. Paris.

DAEVES, K. and A. BECKEL. "*Grosszahl-Forschung und Häufigkeits-Analyse. Ein Leitfaden.*" 8vo, pp. 66. Weinheim/Bergstrasse, 1948: Verlag Chemie, G.m.b.H. (Price 3.20 DM.).

HUME-ROTHERY, W. "*Electrons, Atoms, Metals and Alloys.*" 8vo, pp. 377. Illustrated. London, 1948: The Louis Cassier Co., Ltd. (Price 25*s.*).

KOENIGSBERGER, F. "*Design of Welding in Mechanical Engineering.*" 8vo, pp. vii + 210. Illustrated. London, 1948: Longmans, Green and Co. (Price 18*s.*).

MOON, A. RAMSAY. "*Design of Welded Steel Structures,*" Second Edition. 8vo, pp. viii + 134. Illustrated. London, 1948: Sir Isaac Pitman and Sons, Ltd. (Price 18*s*).

SEARLE, A. B. "*Refractories for Furnaces.*" 8vo, pp. 121. London, 1948: Crosby Lockwood and Son, Ltd. (Price 7*s.* 6*d.*).

SOUTHGATE, B. A. "*Treatment and Disposal of Industrial Waste Waters.*" (Department of Scientific and Industrial Research). 8vo, pp. vii + 327. London, 1948: H.M. Stationery Office. (Price 12*s.* 6*d.*).

VIVIAN, A. C. "*Essential Metallurgy for Engineers.*" Third Edition. London: Sir Isaac Pitman and Sons, Ltd. (Price 12*s.* 6*d.*).

WILLIAMS, G. E. "*Technical Literature. Its Preparation and Presentation.*" 8vo, pp. 117. London, 1948: George Allen and Unwin, Ltd. (Price 7*s* 6*d.*).